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Regulatory Requirements for Implementing Demand Response in the Nordic Electricity Markets

Thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Technology

Espoo 29.10.2015
Supervisor: Professor Risto Lahdelma
Advisor: Timo Partanen, D.Sc. (Tech.)

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Abstract

Demand response is defined as the modification of consumption pattern in reaction to an external signal providing a service within the energy system. It has been recognized as having substantial efficiency potential as part of the liberalized energy markets. The study examines the introduction of demand response in the Nordic electricity markets, aiming at fluent adoption of this resource while obtaining the most profitable outcome concerning the net welfare. The study focuses on three main challenges; a suitable market model, verification, as well as the valuation and net benefits of demand response.

Regarding the market model, the main challenge is defining an optimal mode of operations for the demand response markets. The main question concerns the adoption of separate third party aggregators, independent actors, which would be allowed to collect together a group of flexible consumers and offer their demand reduction to the markets without the consent of the customers' supplier. There is a risk of creating unfair balancing costs to the supplier, which can be resolved by the design of the model. The different possible market configurations were analysed based on their suitability and their effect. The optimal solution was discovered to be a combination of selected models, allowing the participation of a wide range of resources. This encourages competition, which was found essential in achieving the full potential of demand response.

The compensation for demand response is based on the reduced consumption, so there is a need for exact measurement. Demand response is the difference between the normal consumption level that never occurred and the actualized consumption. The most accurate method was discovered to be using a rolling average with some circumstantial correction to create a baseline, which can then be used in calculating the amount of response.

It was discovered that paying full market price for demand response is essential in achieving the desired level of demand response. At the same time, this can create some efficiency losses and adverse effects to the suppliers which is why the net benefits should be investigated more thoroughly. The study concluded that demand response can have a negative net effect depending on the situation, and using mathematical net benefit estimation methods for limiting detrimental flexibility bids seems plausible.

Demand response should be considered as a utility suitable for some situations instead of a comprehensive solution for market inefficiencies. This highlights the importance of assessing the overall effects before applying any changes in the current market structure.

Keywords Demand response, aggregation, electricity markets, regulation

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Tiivistelmä

Kysyntäjousto tarkoittaa kulutuksen muuttamista ulkoisen signaalin ohjaamana, tuottaen samalla hyötyä energiajärjestelmälle. Sen potentiaali arvioidaan erittäin suureksi tulevaisuuden sähkömarkkinoiden tehokkuuden kannalta. Tämä tutkimus keskittyy kysyntäjouston käyttöönottoon Pohjoismaiden sähkömarkkinoilla siten, että kaikki järjestelmän tarjoamat hyödyt saataisiin hyödynnettyä mahdollisimman hyvin. Työ keskittyy kolmeen päähaasteeseen; markkinamallin kehittämiseen, jouston mittaamiseen ja jouston arvon, sekä kokonaishyödyn arviointiin.

Markkinamallin kannalta keskeisin haaste on määrittää optimaalinen toimintatapa kysyntäjouston kannalta. Yksi keskeisin kysymyksistä koskee kolmannen osapuolen aggregaattoreita, itsenäisiä toimijoita jotka kokoavat yhteen usean joustoon kykenevän kulutusyksikön jouston ja tarjoavat sitä markkinoille riippumatta näiden kuluttajien sähkönmyyjän toiveista. Toimintatapaan liittyy riski siitä, että samalla aiheutetaan epäoikeudenmukainen tasevirhe ja siten myös kulu sähkön toimittajalle. Tämä virhe pystytään kuitenkin ratkaisemaan markkinamallin suunnittelulla. Vaihtoehtoisia markkinamalleja arvioitiin niiden soveltuvuuden ja vaikutusten mukaan, ja optimaalisimmaksi vaihtoehdoksi tunnistettiin yhdistelmä toimintatapoja, joka mahdollistaa useiden erilaisten toimijoiden osallistumisen. Tämän nähtiin edistävän kilpailua, mitä pidetään edellytyksenä kysyntäjouston täyden hyödyn saavuttamisessa.

Kysyntäjouston kompensaatiot perustuvat kulutuksen vähentämiseen, joten tarvitaan tarkka metodi tämän vähennyksen mittaamiseksi, sillä kysyntäjousto on erotus normaalin toteutumattoman kulutustason ja toteutuneen kulutuksen välillä. Tarkimmaksi metodiksi arvioidaan rullaavan keskiarvomenetelmän avulla laskettu vertailukulutuskäyrä, jota tarkennetaan esimerkiksi säähän tai vuodenaikaan liittyvillä korjaustermeillä.

Tutkimus selvitti että täyden markkinahinnan maksaminen kysyntäjoustosta on tarpeen jouston tarvittavan määrän aikaansaamiseksi. Tämän todetaan kuitenkin aiheuttavan tehokkuustappiota ja haittoja, minkä johdosta jouston kokonaisvaikutuksia tulisi tutkia tarkemmin. Työssä todetaan, että kysyntäjoustolla voi olla negatiivinen nettovaikutus, ja onkin suositeltavaa käyttää kokonaishyötyä arvioivia matemaattisia metodeja, joiden perusteella haitallisten joustotarjousten täytäntöönpanoa voidaan rajoittaa.

Kysyntäjoustoa ei tulisi tarkastella kokonaisvaltaisena ratkaisuna markkinoiden tehottomuuteen, vaan tiettyihin tilanteisiin soveltuvana hyödykkeenä, korostaen tarvetta arvioida kokonaisvaikutuksia ennen nykyisen markkinarakenteen muuttamista.

Avainsanat Kysyntäjousto, aggregointi, sähkömarkkinat, sääntely,

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Besides my advisor and supervisor, I would like to thank the rest of my colleagues at Energiavirasto for the insightful discussions regarding my study topic as well as the positive feedback at the office.

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Espoo 29.10.2015

Jori Säntti

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List of Abbreviations

ACER	European Agency for the Cooperation of Energy Regulators
BRP	Balance Responsible Party
CACM	Capacity Allocation and Congestion Management
CEC	California Energy Commission
CPUC	California Public Utilities Commission
DR	Demand response
DSF	Demand side flexibility
DSO	Distribution System Operator
DSR	Demand side response
FERC	Federal Energy Regulatory Commission
ISO	Independent system operator
ISO-NE	Independent system operator – New England
LMP	Locational Marginal Pricing
NBS	Nordic Balance Settlement
NCEB	Network Code on Electricity Balancing
NPS	Nord Pool Spot AS
OPA	Ontario Power Authority
RBTS	Roy Billington Test System
RSO	Regional transmission organization
RTO	Regional Transmission Organization
TSO	Transmission system operator
USEF	Universal Smart Energy Framework

1 Introduction

The liberalization of European energy markets, functional international trade of energy between the Nordic countries and the continuous improvements in transmission capacity have led to a more appropriate use of the territorial energy production resources. The European Union's third Energy Package aims at improving the functionality of the EU's internal energy market (The European Commission 2015). On a national scale this has resulted in dismantling of excessive production capacity. At the same time some renewable energy production methods are being heavily subsidized. As a combined result of these, electricity market prices have declined, having a profound effect the profitability of condensing power production. We are facing a situation, where the amount of conventional energy production capacity is declining and the supply of renewable energy is increasing.

While this change in the markets has a positive effect on the environment diminishing the amount of emissions, shutting down of production capacity means that we are more often facing a situation, where the demand of electricity is approaching the maximum production and import capacity. As a result of this, price spikes occur in the markets and at the worst case, the stability or reliability of the network can be threatened (NordPoolSpot 2015b). Currently the main means to cope with these situations are production reserves, and flexible loads in some large consumption units controlled by the transmission system operator (TSO). These resources can resolve the issue of energy inadequacy, but they are only used as a last resort in abnormal situations and therefore do not act as a part of the daily electricity markets.

Traditionally the European energy markets have been more focused on the supply of energy, while the full potential of the demand side of the markets has been underutilized. The European Commission is currently investigating efficient means for developing the energy markets to simultaneously match the energy needs as well as the decarbonizing targets. Enabling the end-users of electricity to actively adjust their consumption is estimated to have a major effect in decreasing peak consumption in the Union scale. This means that the demand of energy in the European energy markets would also include the price-dependent demand of a large group of small end-users instead of considering them merely as a static consumption unit. This change would result in more functional markets, and the improved energy-efficiency would reduce the costs of maintaining the network as well as the need for investing in power production facilities (Conchado and Linares 2010). (European Commission 2013, ACER 2014)

It is evident that demand response will have a very central role in balancing the supply and demand of energy in the advanced energy grids of the future. The European Commission has stated in numerous directives and other publications that empowering the end-users of energy to adjust their consumption according to price-signals will act as an important instrument in the grid of the future. In addition to these, free price formation and advanced energy markets encourage the adoption of demand-response, which is why it can be believed that the first large-scale changes will be seen in the Nordics. (European Commission 2012, European Commission 2009) The technology for wide adoption of consumer participation in the markets is available, but in order to reach the comprehensive optimal end result, some unsolved issues regarding the market model and regulatory aspects have to be resolved. (European Commission 2012)

1.1 Definition of Demand Response

In order to understand demand response, we have to be able to provide a concise definition of demand flexibility. Demand side flexibility (DSF) is a broader concept, under which demand response operates. Eurelectric specifies demand flexibility as "The modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system." The parameters used to characterize flexibility in electricity include the amount of power modulation, the duration, the rate of change, the response time, the location etc. (Eurelectric 2014)." This definition is also used by European Commission´s Smart Grid Task force. (Smart Grid Task Force 2015)

Several kind of activities can be recognized under the concept of demand flexibility. A frequently used classification is division between implicit and explicit DSF, which will also be applied in this thesis. Implicit DSF refers to a situation, where an end user is adjusting the demand of energy according to tariffs, which vary by time. (ACER 2014) In implicit DSF, flexibility is treated mainly in a static manner, because the response in demand can occur several hours after setting the price incentives. In implicit DSF, the time tariffs are commonly repetitive on a daily basis during certain hours, making the effect on the demand somewhat fixed instead of truly adjusting according to the current market situation.

Explicit DSF, is when an end user is adjusting the demand of energy according to a signal, and is rewarded for this change. Explicit DSF operates often at the shortest timescales of response compared to implicit DSF, but in the case of real-time tariffs the distinction between these two can be blurred. Explicit DSF is also called demand side response (DSR), or demand response (DR) which is the expression that will be used in this thesis. (ACER 2014)

The main difference between these two types of demand flexibility is hence the nature of control they have over adjusting the energy demand. Both means are capable of reducing or increasing the load, but as implicit DSF induces an uncontrollable reaction among the market participants, explicit demand response can accurately steer the demand at short time intervals. The amount of change induced by demand response in functional markets is in line with the current market needs, which makes it very suitable for the dynamic smart energy grids of the future.

It is important to understand that demand response includes both demand reduction and increase as a response to the signal (Nguyen, Negnevitsky and de Groot 2011). In this thesis the subject will however be approached primarily from the viewpoint of load curtailment, since the central incentive for the adoption of demand response is inadequate production capacity during peak hours and the potential positive impact DR would have on the market (European Commission 2013). Regardless of this viewpoint focusing on demand curtailment, demand response is not limited to merely limiting the use of energy by switching off energy consuming appliances. It can also consist of other means of adjusting the demand such as efficiency schemes, fuel substitution or embedded generation as long as the action serves as a response to the signal. (ACER 2014).

In addition to the previous definitions, demand response can be divided into two separate forms; dispatchable and non-dispatchable. Dispatchable demand response means, that the flexibility is controlled by a system operator such as the transmission system operator

(TSO), independent system operator (ISO) or regional transmission organization (RSO). An example of dispatchable demand response would be an agreement between the end user of electricity and the system operator, which enables the operator to directly control the customer´s appliance in order to adjust consumption subject to a certain agreed price level or other method of compensation. In contrast to this, non-dispatchable demand response is when the response of an end user cannot be enforced or monitored by a separate party such as the system operator. An example of this would be the real-time change of demand according to the price level in a system among customers, which are charged on an hourly basis. (International Energy Agency 2011)

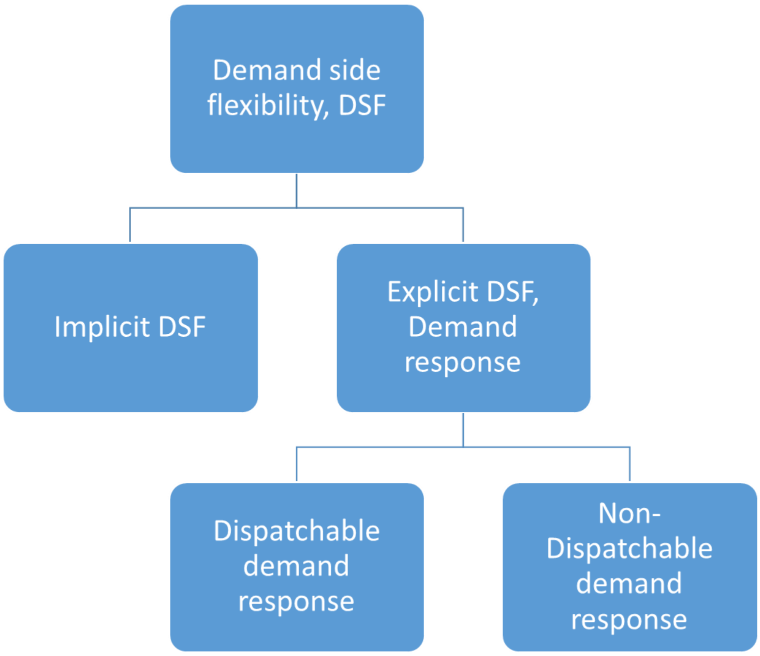

Figure 1. *The different levels of demand side flexibility*

Demand response or DSF does not necessarily alter the amount of energy used in the long run, since it only alters the consumption pattern, moving the consumption from one point of time to another. After the periods of adjusting the demand according to the signal, a catch-up period can be observed (Palensky 2011). For instance, a water boiler can easily be switched off for one hour in order to avoid peaks of high demand without lowering the temperature too much. Regardless of this flexibility, the same amount of energy has to be used after the event to compensate for the switch-off period. Because of this, demand response typically does not save energy, and sometimes even a new peak can be generated as a rebound effect of the initial response (Palensky 2011). The fact that demand response does not decrease the amount of energy used by the consumers does not mean that it is unprofitable from an economic viewpoint. While it does not decrease the demand of energy, the declining demand of power during peak hours helps in avoiding the operation of expensive peak generation capacity as well as in minimizing the required investments in grid capacity. (International Energy Agency 2011)

Traditionally, most of the demand response activities have focused on shifting the energy usage away from the most expensive peak hours in order to avoid costly operation, or investing in new small scale energy production facilities to be used during peaks. Recently, however the activities have shifted towards incorporating the end user as an actual independent actor in the markets, being able to choose whether to purchase energy or not depending on the current situation. (International Energy Agency 2011)

1.2 Why do we Need Demand Response?

The electricity networks are changing radically as we are gradually moving towards a bidirectional flow of energy instead of the traditional dispatchable energy generation where energy flows are directed merely from the big producers to the end users. Since the 1990s, energy markets and power distribution systems have been deregulated and restructured in order to encourage competition in both energy production as well as retail markets. The aim has been in increasing efficiency, lowering the cost of energy and increasing customer participation in the markets. While the target has been improving the energy systems, this change has also had some negative effects on both energy markets and networks. The restructuring of local utilities into energy producers, TSO, retailer etc. can cause problems in maintaining the power supply and network, as the players are facing volatile prices and operating during times of peak demand. (Nguyen, Negnevitsky and de Groot 2011) Numerous independent actors in the field of energy production have identified demand response as a solution for this problem and a central part of the advanced energy markets and grids of the future. (European Commission 2012, International Energy Agency 2011).

In addition to the transformation in the markets, we are currently witnessing the expansion of low-carbon generation. The continuous increase in photovoltaics, wind energy and small-scale energy production will result in a more complex energy system, which lowers the predictability of the energy production requirements. Solar and wind power production facilities produce energy according to the climate, and cannot be controlled. At the same time, the system operators have to ensure that the generation of energy equals demand in real time at any given moment in the electricity network. As the system is getting more complicated and the described changes increase volatility in the markets, balancing and production planning of energy is facing a challenge in how to respond to this new situation. (Smart Grid Task Force 2015) The emergence of alternating energy production capacity would not be a problem, if we were able to adjust the output of other energy production facilities according to the current situation. This however is impossible, since the majority of energy in Europe is produced in large facilities, which are unable to adjust their output, or in plants where it is not financially feasible such as nuclear and conventional thermal power plants. (European Commission 2013) For this reason, demand response and flexibility in general will be essential for the energy markets as well as the electricity grids of the future.

The following **Figure 2** displays the potential of demand as demand response is introduced in the markets. Traditionally, the demand of electricity has been considered to be inelastic regardless of the price level. This is depicted as the vertical line. Elastic demand incorporating demand response is depicted as the sloped demand curve implying that there is variation in the amount of demand according to the price. The supply curve is based on the current power production capacity in the markets according to the production price. The two crossing points of these curves depict market equilibria in these two scenarios. As can be seen, introducing demand response results in lower pricing and reduced power output. On the other hand, the same illustration shows, how the absence of flexibility can result in very high prices. (International Energy Agency 2011) A more detailed elaboration of market economics and the functions of supply and demand curves can be found in Chapter 2.1.

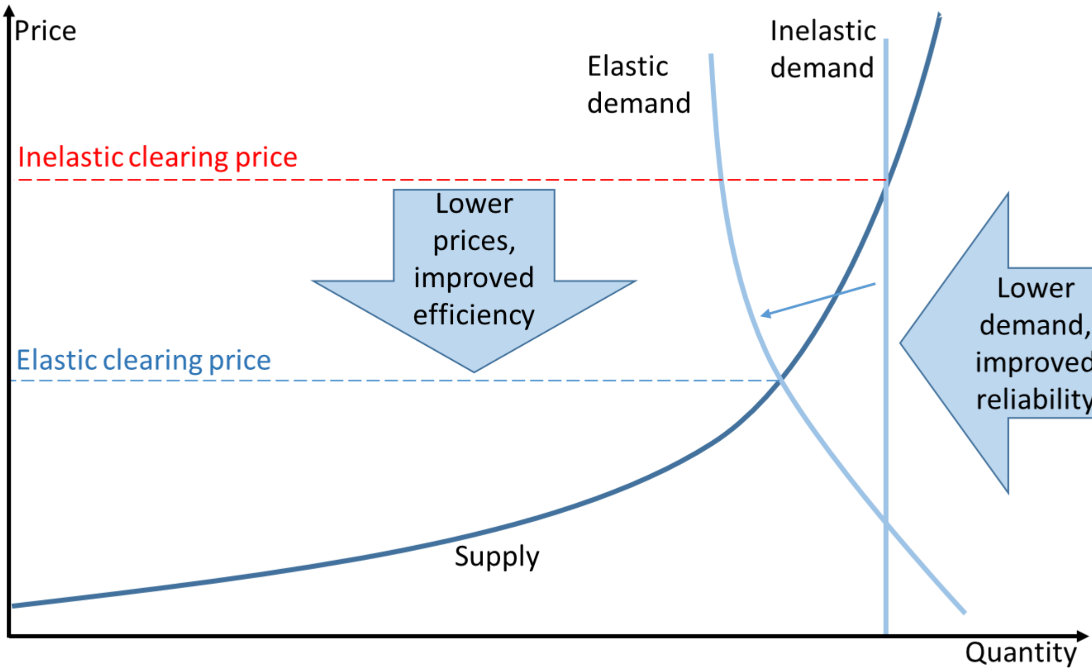

Figure 2. *The potential of demand response in energy markets*

By observing the simplified graphic representation of elastic demand presented in **Figure 2**, one can understand how demand response can provide major advantages on many levels in the power markets if it is executed efficiently. Reducing demand during times of high demand such as long winter periods can allow the grid to operate reliably with lower reserve margins. As a result of this, In the long run demand response reduces investments in expensive generation capacity. The efficiency of price formation is improved, which results in lower prices. Including demand response in the market also makes it more difficult for a large market player to exercise market power. (International Energy Agency 2011) The mechanism, how demand response can reduce is fairly easy to understand. It is however evident that the effect this change has on a market player varies according to the unique needs and aspirations of this actor. One way of mapping these potential benefits is by classifying them by the market sector and the impact they have on the operation and expansion of the markets, which is presented in **Figure 3** (Conchado and Linares 2010). A detailed mapping of the market players can be found in Chapter 2.1.4.

	Operation	Expansion	Market (if liberalized)
Transmission and distribution	• Relieving congestion • Managing contingencies • Avoiding outages • Reducing overall losses • Facilitating technical operation	• Deferring investment in network reinforcement • Increasing the long-term network reliability	
Generation	• Reducing energy generation in peak times • Reducing cost of energy and -possibly- emissions • Facilitating balance of supply and demand • Reducing operating reserves requirements or increase short-term reliability of supply	• Avoiding investment in peaking units • Reducing capacity reserves requirements or increase long-term reliability of supply • Allowing more penetration of intermittent renewable sources	• Reducing risk of imbalances • Limit ingmarket power • Reducing price volatility
Retailing (if liberalized)			• Reducing risk of imbalances • Reduing price volatility • New products • More consumer choice
Demand	• Consumers more aware of cost and consumption, and environmental impacts • Consumers get the options to maximize their utility: opportunity to reduce electricity bills or receive payments	• Investment decisions are made with greater awareness of consumption and cost	• Increase in demand elasticity

Figure 3. *The potential benefits of demand response. An elaboration based on (Conchado and Linares 2010)*

1.3 Approach and Methodology

Demand response is a diverse concept, which combines features from regulation, market economics, legislation and technology. The whole scheme consists of multiple different parties, which have close influence to the actions of the others. The complexity of the research layout and the market composition calls for a pragmatic approach in order to achieve the desired results.

Systems theory is defined as an interdisciplinary study of systems, aiming at discovering patterns and principles, which can be applied to all types of systems in all fields of research. It is considered to be a pragmatic approach to the study of various organizational schemes. These schemes can be divided into three sub systems; closed systems, open systems and complex systems (Morgan 1997). Systems analysis is a formal study method, which aims at recognizing the optimal outcome or the proper course of action. The method aims at recognizing the goals, limitations and options while assessing the possible outcomes regarding risk, expenses or benefits. (Bentley and Whitten 2006) The research approaches the subject by combining factors from both open and complex systems striving to clarify the optimal outcome of introducing demand response. Complex systems approach to scientific studies is based on examining the relationships between separate parts and how they form the collective behavior of a system as a whole, and how the system interacts with its environment. (Meadows 2008) What this means in terms of practice, is that the approach at solving complex problems should be based on reducing or constraining the complexity and analyzing these sections separately. This can be achieved by dividing the whole system into smaller separate parts and analyzing them separately.

A comprehensive review of the market ecosystem is fundamental in applying systems theory, which is why an ample literature summary is presented on the Nordic electricity market features as well as the relevant market economics. This serves as the background of the study, on which the new market model is then built. The model is constructed by first dividing it into three separate main challenges. Each of these challenges is then analyzed reflecting them to the market fundamentals and aiming at the optimal outcome. In the end, the optimal outcomes of these three challenges are combined formulating a single market model, which serves as the recommendation for the regulative requirements in the adoption of demand response.

This study combines the systems theory approach closely to regulatory economics, which provides the limitations and means to assess the outcome of the research. Regulatory economics is determined as the study of legislative actions taken in order to minimize the effect of market failures or distortions. (P. Joskow 1989) In the case of electricity markets it can be seen as minimizing the market errors in order to protect and benefit the market participants. Special emphasis is put on reviewing the effects the regulation has on the economic welfare. (Barak 2012) (Adib and Hurlbut 2008)

It should be noted that the reason for having demand response in the first place is, that we have retail pricing available for the commercial end-users, which in turn interferes with the electricity market structure. Customers do not face the actual market price, but instead a fixed retail price for the electricity, which then leads to distorted demand. What this means is that the regulators are in a sense actually disregarding a major error in the markets, and solving it by additional layers of regulative action and market structures. This situation is a result of the political willingness to maintain the retail electricity prices at a certain level, and can in fact be acceptable. At the same time it also changes the approach one has to take in addressing the issue. Due to the inherent errors in the markets, it might be difficult or even impossible to discover a flawless solution for the problem of introducing demand response in the markets. Hence, some disadvantages in the provided market model can be considered to be acceptable. What this means regarding the approach of the study is that the reasoning and justification of the solution should emphasize the relevance of the total economic welfare.

1.4 Scope of the Study

Even though demand response is recognized as an essential part of the future grids and energy markets, the adoption of this technology has been low. Regardless of this, the regulatory authorities regarding energy production should have a stand on how to prepare for demand response. By examining the practices in existing flexibility markets, it is possible to prepare for this change in the markets, and form a suitable legislative framework before the actual adoption of this technology. In addition, this is most likely the only way to achieve an optimal outcome.

This thesis is funded by the Finnish energy regulator, Energiavirasto. The focus of this study is thus in forming a Finnish regulatory framework for the Nordic energy markets. The Nordic energy markets consist of the liberalized wholesale electricity markets in Norway, Sweden, Finland, Denmark and the Baltic countries. It should be noted, that the regulations may vary slightly depending on the market structure in question.

In this thesis the focus is mainly on the wholesale and retail markets of electricity. There is currently no actual jurisdiction or a market model, which would incorporate the whole array of demand response services available for these open markets. Due to this, the possibility of creating market distortions or failures is evident and the introduction of profitable demand response resources in the markets can be considered unlikely. Consequently, the retail and wholesale market is also the sector, where Energiavirasto has most influence and jurisdiction. The strategy statement of Energiavirasto states the goals as developing the energy markets, regulation energy efficiency and the security of supply for energy (Energiavirasto 2012). What this means is that the study will not be concentrating on the use of flexibility for network balancing purposes or ancillary services such as frequency containment reserves, frequency restoration reserves. Interruptible contracts between the TSO and industrial consumers are also outside the scope of this study, as they have little to do with open energy markets.

The focus on the umbrella of terms falling under the demand flexibility will be specifically on explicit demand flexibility ergo demand response as defined in Chapter 1.1. The focus and goal of the study is in finding the optimal operating policies on the open electricity markets, and implicit flexibility relates to the retail rate or tariff structures created by the suppliers. For this reason they have little significance concerning the market operations.

As this is a thesis aiming at improving the functionality of the energy markets, the study will not address the technical aspects such as smart metering, data transfers or possible grid challenges caused by demand response. The lucrativeness or profitability of demand response is considered mainly from a macroeconomic perspective, by creating a level playing field for all actors in the energy markets incorporating flexibility.

As explained in Chapter 1.1, demand response is an important resource, which can be beneficial in various different uses for network congestion or various markets. The focus of this thesis is however specifically in the wholesale and retail electricity markets. The reason for this scope of studies is that there is a major potential to be unleashed Coincidently, this is also the field of demand response, in which there are unresolved issues to be solved before implementing the demand response systems on a larger scale. These issues consist mostly of the design of the market structure, the resulting balancing errors and questions about proper compensations for this resource. The various uses of demand response and the scope of the study are presented in **Figure 4**.

<table>
<tr><th></th><th>Capacity</th><th colspan="4">Market</th></tr>
<tr><th></th><th>Management</th><th>Interruptible contracts</th><th>Ancilliary services</th><th>Balancing</th><th>Wholesale / Retail</th></tr>
<tr><td rowspan="2">Capacity</td><td rowspan="2">Demand flexibility as an alternative to network reinforcement</td><td rowspan="4">Specific interruptible contracts concluded by the TSO with industrial consumers</td><td rowspan="4">Demand flexibility participation to the procurement of frequency containment reserves (FCR) and frequency restoration reserves (FRR)</td><td rowspan="2">Demand flexibility participation to procurement of manual reserves</td><td rowspan="2">Demand flexibility participation to CRM (if implemented)</td></tr>
<tr></tr>
<tr><td rowspan="2">Energy</td><td rowspan="2">Demand flexibility for congestion management purposes</td><td rowspan="2">Activation of flexibility bids</td><td>Suppliers internal portfolio optimization through dedicated supply prices</td></tr>
<tr><td>Direct flexibility participation to the wholesale market</td></tr>
</table>

Figure 4. *Schematic presentation of the different uses of flexibility highlighting the focus of this study.*

The fact that there is a relatively advanced liberalized market for electricity in the Nordics and large coverage of smart metering increases the importance of studying demand response. Even though these factors should provide an applicable basis for multiple types of demand response services, there has been a lack of such programs.

1.5 Aim of the Study

While the Nordic energy markets are liberalized and can be considered advanced, it seems that regulating the market rules in order to achieve highest societal welfare is necessary in the energy markets (Adib and Hurlbut 2008). Observing various energy market reforms has also revealed that redesigning a market should be conducted as a planned transition towards a model incorporating the current basic ingredients of a functional market. Most of the unwanted and unexpected outcomes in energy market reforms have been the result of misguided design or fumbling implementation. (Sioshansi 2008)

The purpose of this study is to form a comprehensive view of implementing demand response from the perspective of the national energy regulator. The aim is at clarifying the possibilities to encourage the adoption of demand response in the Nordic energy markets, and the requisite depth of regulatory oversight.

The following research question is formulated in order to respond to the objectives of this study: *"What kind of a regulatory framework should we implement in the Nordic electricity markets to deploy unbiased demand response resources in the markets"*. This objective has been divided into three subquestions to clarify the aims more precisely. By answering to these questions, it is possible to form a regulatory model, which is then used as a basis for creating the foundation for demand response as a part of the revised energy market model.

The research subquestions are stated as follows:

1. *What is the value of demand response and how can we ensure that we are gaining the full potential of this resource?*
   There is a question regarding the value demand response can provide to the markets and the net benefits of implementing this new scheme. There are also some implications of a risk of demand response possibly having a negative net effect in some situations. It is thus important to examine how this utility should be handled in order to obtain the full potential without the drawbacks.

2. *What kind of market model should we adopt for demand response?*
   There are multiple different methods for offering demand response in the markets, which often are also market specific. The current legislation does allow certain types of demand response, but would there be need for expanding the options? There are also major questions regarding balancing, unjust expenses and the role of a separate third party demand response aggregator, which need to be resolved before applying any changes. The available and potential market configurations are examined and each of these is analyzed to discover the optimal variation to be adopted in the Nordic markets. The aim is at forming a market model, which enables economical demand response on a level playing field without causing negative effects to third parties or other market distortions.

3. *How can we verify that a demand response event took place?*
   Demand response is defined as the difference between the level of reduced consumption and the normal level of consumption, which never occurred. The compensations for demand response should be based on verified events, which is why there is a need for having a common reliable method to measure the flexibility. The study takes a look at the different options available and gives a suggestion to be adopted in the Nordic markets.

4. *How could the Nordic regulatory authorities contribute to the adoption of this new resource?*
   As the national regulatory authority, Energiavirasto has a great potential for encouraging the adoption of demand response. Based on the previous subquestions and relevant findings, set of recommendations is presented for the regulators regarding optimal handling of the situation.

Based on the research subquestions it is evident that the aspirations of this thesis are ample and challenging. It is however recognized that each of these questions is closely linked to each other and that resolving these issues was found to be essential in order to produce the results, while focusing only on a subset of these might lead to an excessively vague outcome. This thesis aims at providing a comprehensive outlook on how demand response should be treated in the Nordic electricity markets and offering a direction for further studies regarding the large-scale adoption of the utility.

1.6 Structure of the Thesis

This thesis begins with an introductory chapter concerning the exact definition of demand response and the research topic. In the first chapter the study determines the research question and clarifies, why this study is significant based on the background and expected future changes in the electricity markets. Further, the introduction addresses the objective of the study, incorporating the methodology. Also the scope of the study is defined. The introduction is followed by a study on the theoretical framework consisting of an overview of market economics relevant to demand response, and mapping of the existing market models and regulatory structures based on literature. A synthesis is formed based on the theoretical framework, which is then used to draw conclusions regarding the research questions.

The second chapter concerns the theoretical framework. First the essential theories of market economics regarding demand flexibility and electricity markets such as supply, demand, price formation and price elasticity of demand are reviewed. The section explains the market functions in order to understand how the market forces interact. The framework is then elaborated by taking a look at the Nordic electricity markets. The study examines the different actors in the markets, and their individual partially conflicting interests and aims concerning the scope of this study.

The third chapter presents an analysis based on the framework introduced in chapter two. A general view of the different regulatory and market models in use at the moment is presented, after which, the study builds on the given energy market preconditions and formulates a justified view answering to the research questions. The study first addresses the issues of measuring the amount of flexibility and the net benefits of demand response. This is followed by examining the various market models and their suitability. Each model is analyzed individually to discover the optimal market configuration regarding demand response in the Nordic markets. After this, the study examines the most accurate methods for measurement and verification of demand response to be adopted. The third chapter concludes by estimating the suitability of the selected models, as well as examining the required modifications to apply these solutions as well as some related questions. Special attention is also given to possible market failures or distortions.

The fourth and final chapter consists of the conclusions of the thesis, which aim at summarizing the entire research. The study presents the findings and recommendations for the regulatory authorities regarding the deployment of demand response in the Nordic electricity markets. Possible themes for further research are also identified and discussed. The relevance of the study is assessed both as a scientific study as well as a guideline for the regulators in responding to the changing environment. The chapter concludes by listing individual recommendations for actions for the Nordic regulators.

2 Theoretical Framework

2.1 Demand Flexibility and Market Economics

Reviewing the basic fundamentals of market economics is required in order to understand how liberalized electricity markets function and how the individual actions taken by market players affect the market. The formation of demand and supply curves and how they bring the market participants together is presented. This basic theory is then elaborated to cover the specifics of electricity trading on a liberalized market. In order to understand the challenges of implementing new demand response regulation, the study introduces the various different parties operating on the markets, as well as their interests and ambitions. As discussed in Chapter 3.3.1, new regulatory principles should aim at creating a level playing field for all the market participants. In order to do this, this chapter is concluded by taking a look at the possible conflicts between the market players.

2.1.1 Demand, Supply and Price Formation

The demand curve is a graphic interpretation of how much consumers are willing to pay for a commodity. The presumption is that any consumer has a possibility to choose over which products to consume, and that the consumers are facing scarcity. This means that they have limited resources, which forces consumers to make choices regarding how much resources one is willing to use for each individual commodity. These choices reflect the consumer's own needs, and the perceived value of various commodities. It is assumed that each consumer is pursuing the maximal utility within the budget constraints set by the resources. The fundamental theorem of demand applies this assumption to the price and demand of a product, stating that the rate of consumption falls, as the price of the product increases. A similar simplified reasoning can be presented also based on the amount of products consumed. The first commodity, such as a pair of shoes is valuable to a person walking barefoot, but the subjective benefit of acquiring a second pair is lower. This is called diminishing marginal utility, and is the reason for the shape of the demand curve. The demand curve for a single consumer might be a straight line, and it is often more useful to form a curve representing the demand as a whole. This can be done by adding up the all the individual customers. An example of forming a demand curve from individual linear demand curves is presented in **Figure 5**. The individual demand curves of single consumers are denoted as D1, D2 and D3, and the total demand curve as D123. The market demand curve is the total sum of all individual demand curves. This results in a downward sloping curve presented in **Figure 6**. Price is measured on the vertical axis and the amount on the horizontal axis. (Parkin 2014)

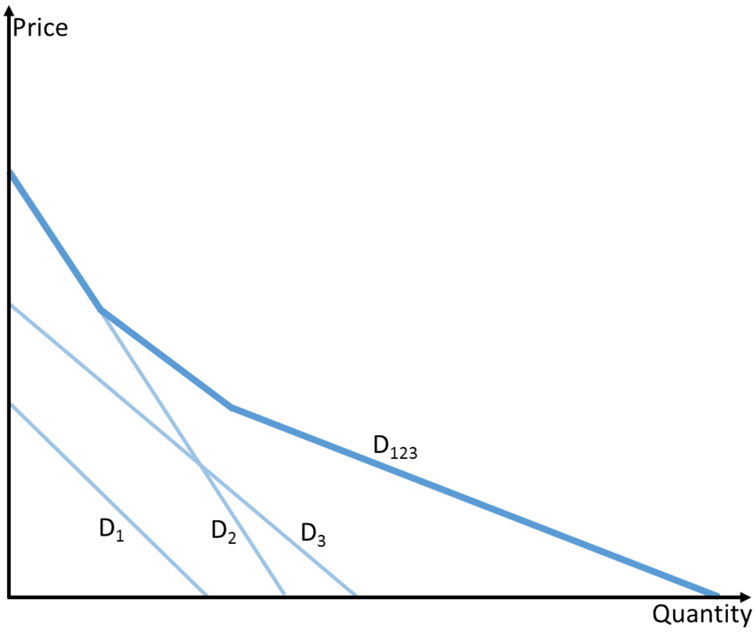

Figure 5. *Combining the individual consumers' linear demand curves*

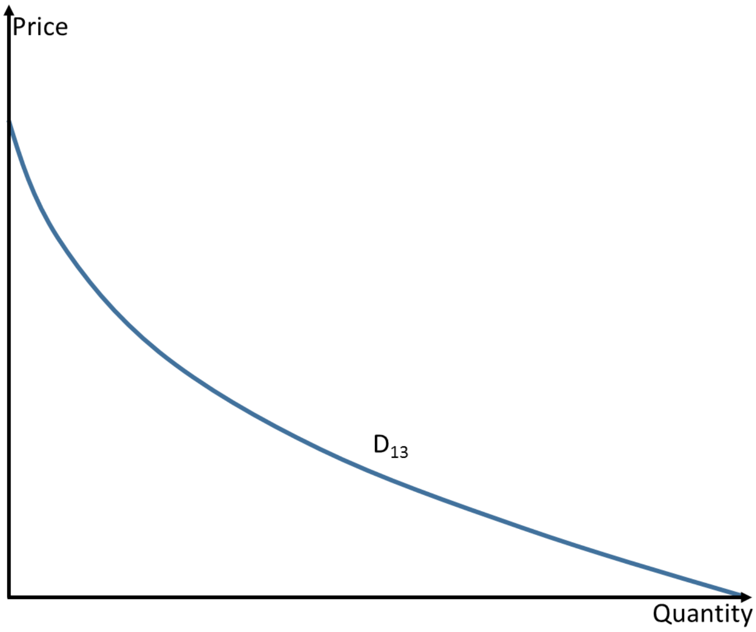

Figure 6. *The demand curve*

The demand curve expresses the relation between price and the amount of this commodity the consumers are willing and capable of purchasing at this price. This can be done for instance by selecting any point on the curve and reading the corresponding price value horizontally on the y-axis and the amount of consumption by reading the value vertically on the x-axis. It is used to estimate and portray the consumers' behavior in competitive markets. (Parkin 2014)

The supply curve is analogous to the demand curve. It is a visualization of the relationship between price and the quantity of this commodity that a seller is willing and able to supply. The interpretation of this curve is similar to supply curve. The reason, why the supply curve is sloping upwards is a result of the companies' aim at maximizing their profits. Any profits made by the company are a result of sales margin, which is the difference between the income and the expenses. This income is a result of selling the products. It is assumed that under perfect competition supply is determined by the marginal cost of the commodity in question. Marginal cost is the change in total cost when the output of a company is increased by one single unit. It is best described as the varying tangent of the marginal cost curve, which is presented in **Figure 7**. According to this, any company will increase the output until the cost of producing additional units is more expensive than the price they would receive for selling this product. The supply curve is based on the marginal cost curve. If the supplier were to exceed the optimal marginal costs, the losses would have to be compensated in a higher price. This results in a curve sloping upwards. (Parkin 2014)

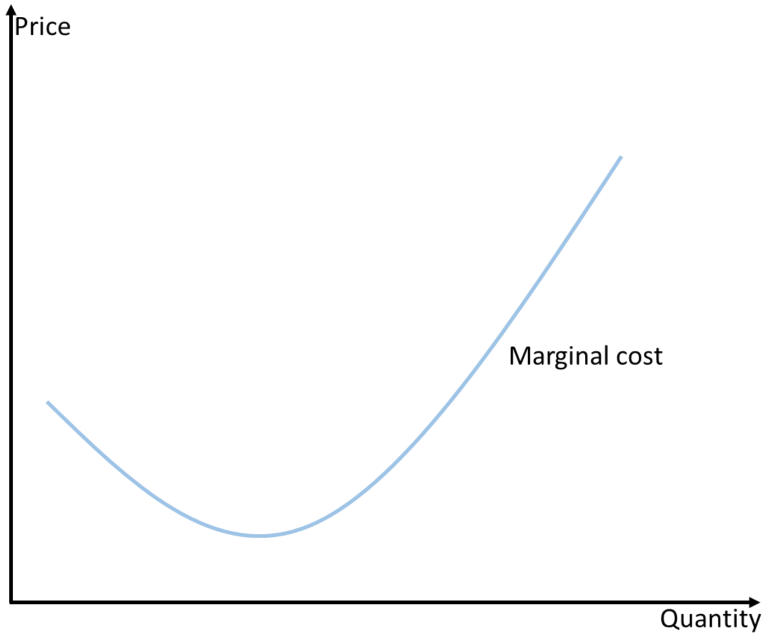

Figure 7. *The Marginal cost curve*

In order to understand how the markets work and how market players interact, we combine the two curves in one single diagram. The fundamental assumption is that each consumer and supplier accept the prices given by the market, and that each individual player has little power to affect the market price in these open markets of perfect competition. Each market player is pursuing their own optimal price and there is a tendency for the price to vary until the market reaches a balance. This is called the market mechanism, and it results in the quantity supplied and demanded being equal. Market balance is visualized as the crossing point of the demand and supply curves. (Parkin 2014) This is presented in **Figure 8**.

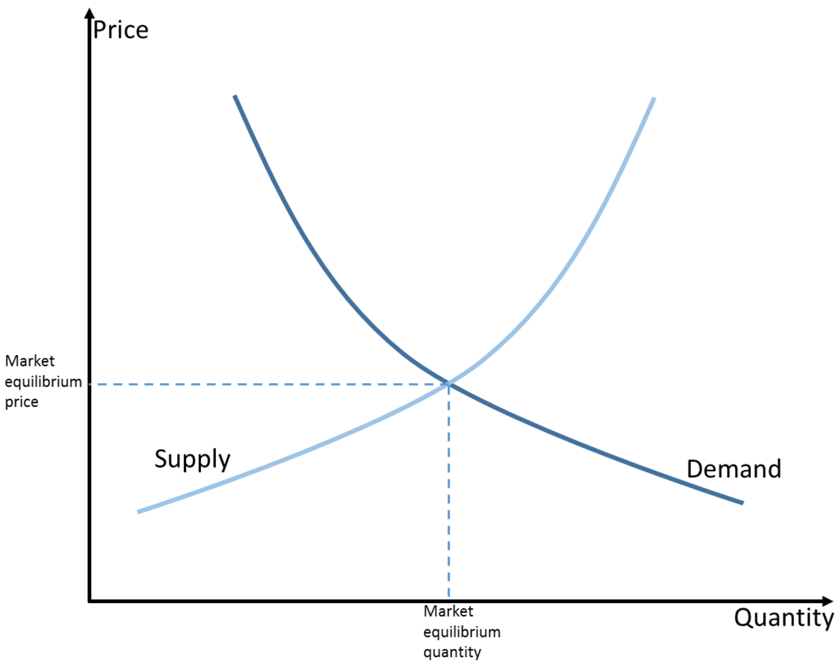

Figure 8. *Market balance*

While introducing the theory regarding the basics of market economics, some assumptions were made in order to introduce the theories. Regarding the validity this study, it has to be ensured that the theory applies in the specific market in question, such as the Nordic electricity markets in this study. While outlining the demand and supply curves, it was assumed that any given quantity would be produced and sold, regardless of the price. This makes sense only, if there is at least a roughly competitive market for the commodity in question. In practice this means that the sellers and buyers have little market power over the prices. Should the markets be controlled by a single monopolistic supplier, the relation between price and quantity would not apply any more. The monopolist producer would be able to affect the prices, for instance forcing the price to be fixed, while changing the quantity supplied. It should be understood that the model of supply and demand is applicable only, when one is applying it to a competitive market consisting of numerous suppliers and consumers. (Parkin 2014) Hence, in the case of Nordic electricity markets the introduced market theory can be considered valid, as there are numerous parties on both demand and supply side. A detailed review of the Nordic electricity markets can be found in chapters 2.1.3 and 2.1.4.

2.1.2 The Effect Demand Response has over Market Equilibrium, and Price Elasticity of Demand

To understand the mechanisms how demand response can decrease both the demand of electricity as well as the cost of electricity, one has to understand how different changes in the supply and demand affect the market equilibrium. The study will first review these changes in general from the perspective of market economics, after which this is applied for demand response in the electricity markets. (Parkin 2014)

The supply and demand curves should not be considered static, but instead as a varying projection of the current market situation. **Figure 9** presents, how the quantity of demand for a certain commodity changes as a result of an increase in the consumers' incomes. Should the commodity prices remain static, we would see an increase in the quantity of demand, represented as the change from Q_1 to Q_2. On the other hand, we can also interpret the situation asking how much a single consumer would be willing to pay for a given quantity of the commodity, which is represented as the change from P_1 to P_2. Regardless of the viewpoint, the demand curve as a whole will shift to the right. A shift in the position of the demand curve can occur also based on other things than an increase in the income. A change in the perceived value of a product affects how much the consumers are willing to pay for the commodity in question, again shifting the demand curve. (Parkin 2014)

Similar movements can be observed also in the supply curve. If the supply of the commodity is increasing, the supply curve shifts to the right, which is presented in **Figure 10**. Correspondingly, decreasing supply shifts the supply curve to the left. The reasons for a change in the quantity supplied can be a result of various variables in addition to price. Production cost, wages and cost of raw materials all have a significant effect on the quantity supplied. As an example of this, lowered raw material costs increase the output shifting the supply curve to the right, provided that the price remains the same. (Parkin 2014)

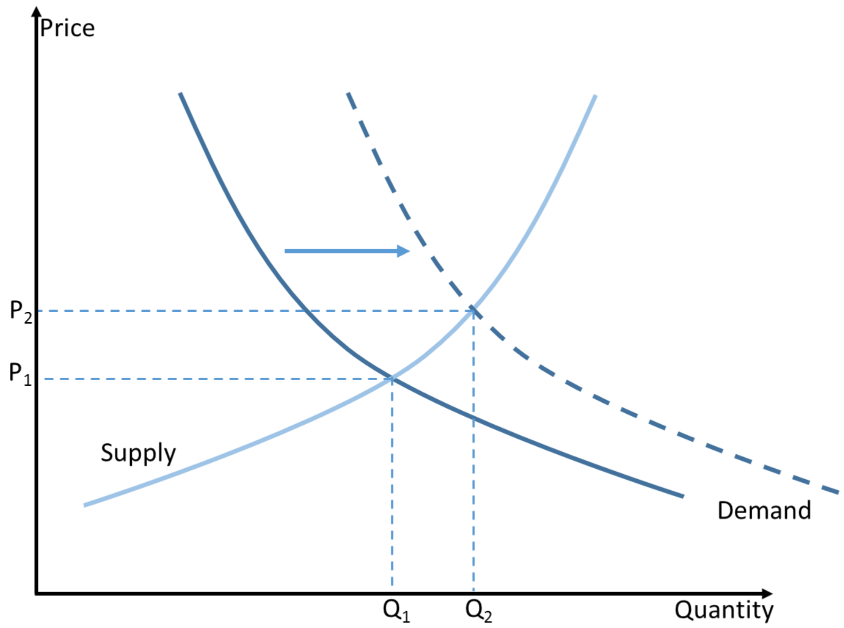

Figure 9. *The transition of the demand curve and the effect on market balance*

As demonstrated above, the demand and supply curves are constantly moving as a response in changes in the environment or other factors, and the market mechanism results in an equilibrium in the intersection of the two curves. It is hence evident that the shifting curves change the location of the market balance, also known as the market clearing point. This means that the equilibrium prices and quantities also vary depending on the current market situation. A shift in the supply curve is introduced in **Figure 9**. Let´s consider a similar shift for example as a result of lowering production costs and examine its effect in the market balance. **Figure 10** presents a situation, where the supply curve has shifted from S to S´ similarly as in **Figure 9**. As a result, the market price decreases from P_1 to P_2. At the same time the total quantity produced increases from Q_1 to Q_3. This is consistent with the intuitive assumption. Lower production costs result in lower prices and increased sales. Analogously, an increase in the production costs would cause an opposite result; the supply curve would shift to the left, prices market prices would increase and the total quantity would decrease. (Parkin 2014)

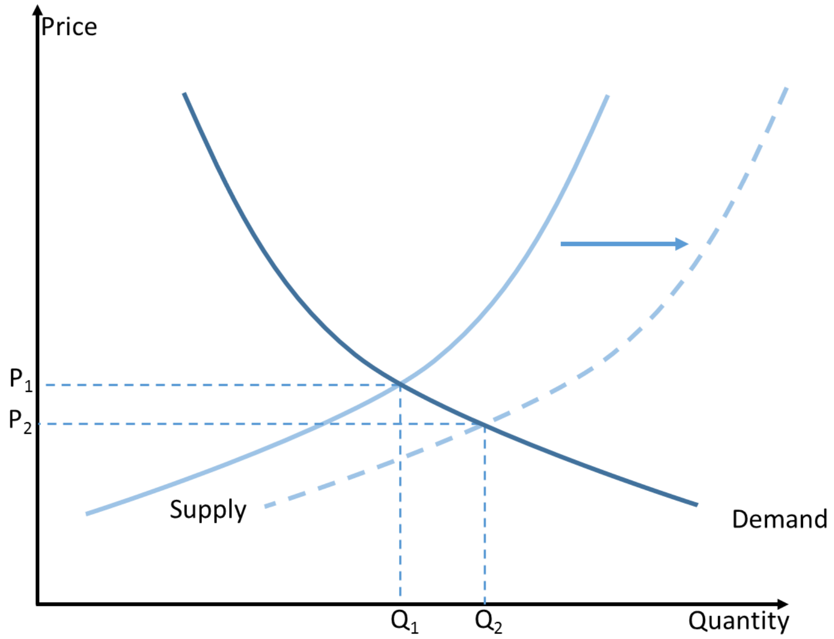

Figure 10. The transition of supply curve and the effect on market balance

In most markets however, both demand and supply curves are shifting repeatedly. The economic situation and fluctuating needs depending on the time of the year affect the demand of a certain commodity. The resulting market equilibrium depends on the shape and how much the curve is shifting. **Figure 11** presents how the new market balance is formed as a result of both demand and supply curves shifting. The resulting quantity of demand for the commodity or the price can be hard to predict, unless the dependence of supply and demand on price and other variables ergo the shape of the curves are well known. In the case of electricity markets, the shape of the supply curve is largely based on the existing power production facilities and therefore well known. (Parkin 2014)

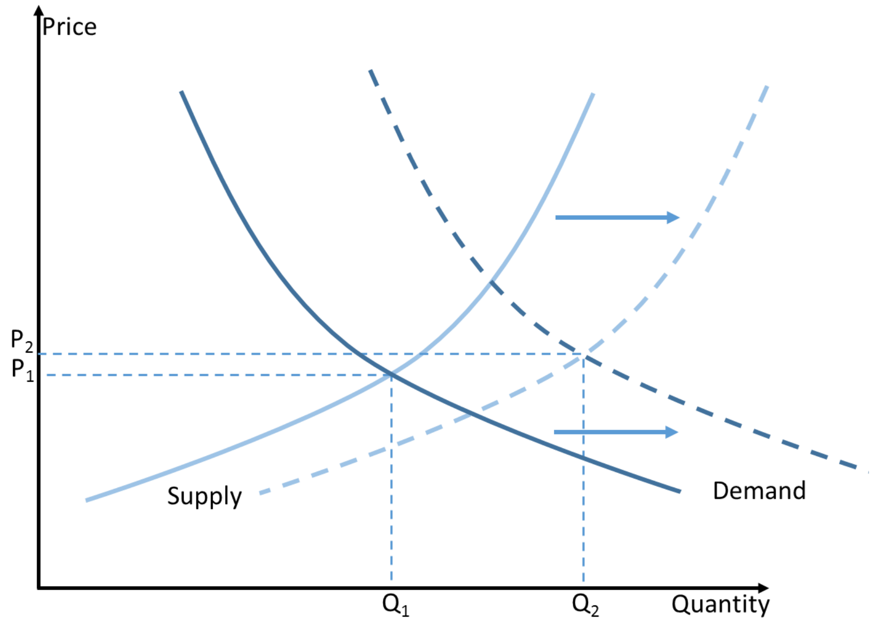

Figure 11. *The new market balance as a result of the movement of both demand and supply curves.*

In addition to the introduced concepts, there are some essential definitions to be understood regarding demand response and market economics such as substitutes, complementary goods and elasticities. Substitutes are two commodities for which an increase in the price leads to an increase in the quantity of the other. (Parkin 2014) For example other means of flexibility such as oil fired backup power stations could be considered as a substitute for demand response. Analogously, commodities are complementary, when an increase in price of one results in decrease in the quantity demanded of the other. Elasticities of supply and demand in turn represent the change in a variable resulting from an increase in another. It is often used to describe how much the quantity demanded will change according to a 1-percent change in the price level. This is called price elasticity of demand. (Parkin 2014) Denoting quantity as Q and price as P, it can be written as follows:

$$E_p = \frac{\%\Delta Q}{\%\Delta \mathrm{P}}$$

Equation 1. *Price elasticity of demand*

The price elasticity of demand results usually in a negative number, because the quantity demanded usually falls as the price increases. It is however common to only present the magnitude of change using only the absolute value of the flexibility instead of the negative value.

As mentioned in Chapter 1.2, the demand of electricity has traditionally been considered inelastic. Inelastic demand means that the demand of electricity is permanently at a fixed quantity, which can be illustrated as a straight vertical line as the demand curve. (International Energy Agency 2011) It would seem evident that the demand does not remain constant as the prices vary from time to time. It is however impossible for an end user to adjust the electricity used – ergo to form an actual demand curve – if the price signals do not reach the actual users of electricity, or if there is no market mechanism to produce value for these actions.

Should demand response be introduced into the markets, the quantity of demand would alternate depending on the price, as the individual end users optimize their electricity usage according to the current situation. This is illustrated as the sloped demand curve in **Figure 2**. (International Energy Agency 2011) As can be observed, demand response results in lower pricing and reduced power output. (International Energy Agency 2011) The following chapter explains in detail the functions of price formation in the Nordic electricity markets and how to apply demand response according to the theories introduced in this chapter.

2.1.3 The Nordic Electricity Markets

According to Hunt and Shuttleworth (1996), there are four different basic electricity supply models, for which the evolution towards fully competed markets can be divided. The first model is a *traditional monopoly*, in which there is one utility, which is responsible for the generation, transfer and distribution of electricity, or alternatively one generation and transmission utility, which sells all the electricity to a local monopoly distribution company. In the second market development stage, an independent power producer is introduced to the markets. This producer is connected to the network and allowed to sell the electricity to the utility acting as a purchasing agent. This *purchasing agency model* can evolve further to a stage, where the generation capacity consists only of independent power producers. At this stage there is some competition between the power producers, but the rates of electricity have to be regulated because of the monopoly situation of the purchaser. The third developmental stage of the electricity markets is *wholesale competition,* in which there is no central party responsible for provision of electricity. Each of the distribution companies purchase electricity according to the total demand of their companies from the generating companies from a wholesale electricity market. At the retail level there is however still a centralized operator, because each of the distribution companies is responsible for operating the regional distribution network and purchasing the electricity on behalf of their own customers. Compared to the previous model, wholesale competition induces a lot more competition between the generating companies, as the price is determined on the markets according to demand and supply. The price for the end customers however has to be regulated, because there is no freedom of selecting the supplier. The fourth and ultimate form of competitive electricity markets is called *retail competition*, in which every customer has a possibility to select their own supplier of electricity. The retail prices no longer have to be regulated, because the customers have a possibility to change their own retailer. The only remaining monopolies are operating the transmission, and possibly the distribution network. The expenses of the network are covered by payments by all the network users. These charges have to be regulated, as the networks still remain monopolies. (Hunt and Shuttleworth 1996)

Finland, Norway, Denmark and Sweden started to liberalize their energy markets in the 1990's opening them to a stage of retail competition forming what is now called the Nordic energy market (Hunt and Shuttleworth 1996). At first, these countries only opened their own national markets. This however soon led to forming an open electricity market to cover the whole Nordic area, as the potential benefits of doing so became evident. (NordREG 2009) The changes in the electricity markets were made to introduce competition in electricity generation and selling, while the transmission and distribution networks were to remain natural monopolies, as they still are. One of the most important goals of deregulating was to promote the efficiency of the electricity supply industry. The traditional vertically integrated monopoly of generation, selling, transmission and distribution had led to a situation, where significant cost savings could be achieved by introducing competition in the markets. (Viljainen 2005) (Tahvanainen 2010)

Energy market liberalization is defined in the European Commission’s third energy package directive as the freedom of selecting the supplier of electricity and vice-versa the freedom of all suppliers to deliver electricity to their customers. The directive advocates ownership unbundling, which means separating the electricity production from transmission operators. The aim in this is to avoid the inherent conflicting interests and to ensure security of supply. (European Commission 2009) This directive is enforced in each of the Nordic countries’ own legislation in a similar fashion. For example in Finland the Electricity Market Act states that any company operating in the electricity markets has to separate the grid operations from other electricity trade, and the electricity business units from other business activity conducted by the company (The Finnish Government 2013). The electricity markets in all the Nordic countries are organized so that the grid companies have a status as a local monopoly, which is hence subject to regulation. Regardless of this, each customer can select their own supplier of electricity. (NordREG 2009) (Tahvanainen 2010) (Viljainen 2005)

The trade of electricity in the Nordic countries is conducted on Nord Pool Spot AS (NPS), which is a power market owned mainly by the Norwegian, Swedish, Finnish and Danish transmission system operators and the Baltic countries by a smaller share. NPS is licenced by the Norwegian Water Resources and Energy Directorate, and as a company registered in Norway it operates under Norwegian law. (NordPoolSpot 2015a)

The most central trading area in NPS is the day-ahead market, Elspot. It operates every single day and there are over 350 buyers and sellers, of which most trade on a daily basis. On the Elspot market, each of the market participants is estimating its operations for the following day. The producers of electricity try to estimate how much they can deliver at each hour of the following day. They also set their price level for this amount of electricity. Correspondingly, the purchasers of electricity make an estimate of the electricity required during each hour and set the price they are willing to pay for it. All the bids and orders are entered into the Elspot trading system, and none of the active market players is aware of bids made by others. After the daily closing hour of 12:00 CET, which is the deadline for submitting bids for the following day, all the purchase bids and production bids are merged into the demand curve and supply curve correspondingly as explained in Chapter 2.1.1. An algorithm is used to calculate the market equilibrium consisting of the system price and volume, which is then published for each hour of the following day. This is presented in **Figure 12**. The main function of the markets is to pool all the bids on the markets in order to produce electricity at the lowest possible price. There are multiple bidding areas in the Nordic markets, and to relieve congestion, some area prices are set higher to reduce demand in these areas affected by insufficient transmission capacity. After the hourly system prices are set by the algorithm, the actual area prices are determined according to the transmission capacity available for the area in question. (NordPoolSpot 2015a)

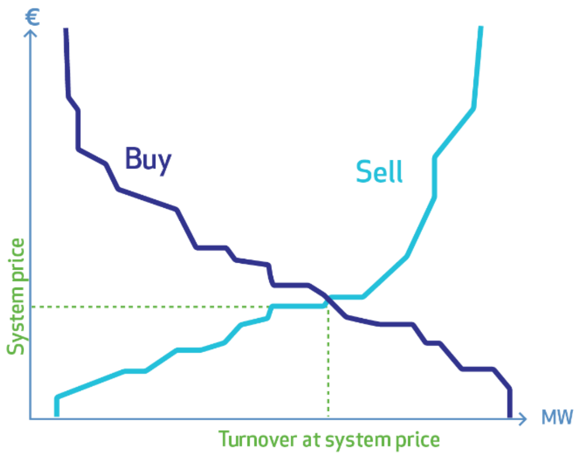

Figure 12. *Price formation in the Elspot markets (NordPoolSpot 2015a)*

In addition to the Elspot day-ahead markets, NPS operates an intraday market, Elbas. As the majority of the trading volume is conducted on the Elspot market, the role of Elbas is in ensuring that the balance between production and demand of electricity matches at a shorter time interval. As the day-ahead trade is cleared 12 hours or longer before the actual delivery hour, it is not uncommon for an incident to occur affecting the production capacity. A fault in a large production facility or a change in the wind conditions may cause lower power generation than anticipated. Elbas is traded close to real time, every day until one hour before the delivery, so it makes it possible for the buyers and sellers to bring the market back to balance. Contrary to the day-ahead markets, trading at Elbas is based on a first-come first-serve principle. This means that the highest buy price and the lowest sell price comes first. (NordPoolSpot 2015a)

In addition to the introduced two markets maintained by Nord Pool Spot, there is an additional balancing market. Let´s first take a look at balancing as a concept. The Finnish TSO Fingrid defines balancing as maintaining the continuous power balance between electricity production and consumption (Fingrid 2015). This constant balancing has to be done in order to maintain network stability at all times. Regardless of the day-ahead and intraday markets' tendency to discover the amount of demand at each moment, there are always unexpected circumstances such as changes in consumption, weather or grid conditions, which make it normal to have some imbalances occurring in the system. (NordREG 2010)

In order to maintain balance, the national TSO in the Nordic countries has balancing agreements with different Balance Responsible Parties (BRP). Each of the BRPs has to make a plan regarding their electricity consumption and supply them to the TSO. This plan acts as a baseline for the consumption, and the BRP is financially responsible for any deviation from this plan. This acts as a strong incentive for precise planning and forecasting of the electricity usage as exactly as possible until the TSOs gate closure time an hour before the actual operating hour. It is mandatory for all the consumption, production and grid connection points to have a BRP, and each trader, producer or supplier has to either act as a BRP themselves or have a standing contract with one to handle the balancing. In the case of large end users of electricity with the required know-how and resources, it is also possible for a consumer to act also as a BRP. There is some difference between the Nordic countries' regulation regarding balancing, but the procedures are in the end very similar. (NordREG 2010)

The Nordic electricity markets have become highly united and the wholesale markets are truly uniting the different national grids. The whole area is characterized by cross-border balancing, where the adjustments will be made with the least expensive method just as long as there is transmission capacity available. It can be said that the Nordic electricity markets form one unified balancing area. Consequently, there is an ongoing process among the Nordic countries to unify the balancing methods called Nordic Balance Settlement (NBS) (NordREG 2009). Regarding demand response, the most likely market to require special attention is the balancing market. The European Commission's Expert Group on smart grids has recognized some potential problems regarding the effects demand response might have on the Balance Responsible Party. (Smart Grid Task Force 2015) Elaboration on the balancing issues related to introducing demand response can be found in Chapter 3.3.2.

2.1.4 Independent Parties on the Demand Response Markets

As mentioned in Chapter 1.5, the aim is at creating a regulative model, which enables a level playing field for the different market players regarding demand response. There are numerous individual actors in these markets, each of which having their own, possibly conflicting interests. In order to understand how and why do these actors interact in the electricity and demand response markets, one has to take a closer look at these market players. The relevant market players are assessed individually, disclosing the main motivators and risks they have regarding demand response.

Electricity *retailers* purchase electrical energy from the producers at a price level determined by the market forces. A margin is added to the purchasing price, after which this electricity is sold to a large number of consumers. Just as any retailer, they try to estimate the amount of electricity to purchase by evaluating the demand among their consumers. Based on this demand forecast, the retailer develops a purchasing strategy in order to maximize profits. (Kirschen and Strbac 2008) This approximation of demand is conducted for each hour separately, just as the purchasing bids. As discussed in Chapter 2.1.3, any deviation from the planned consumption of electricity results in imbalances in the balance settlement, and hence in additional costs for the retailer. This system provides an incentive for the consumer to maintain the balance as precisely as possible. Caves and Eakin (2000) argue that the demand estimates made by retailers are unfit for predicting demand spikes, which can lead to major financial problems among the retailers. The adoption of demand response would thus provide a tool for the retailer to mitigate risks.

The *TSO* has the operative responsibility of the network, maintaining the security of the transmission system. In this case security means assessing whether the network can withstand unexpected faults. The TSO prepares for these contingencies by various means. (Nguyen, Negnevitsky and de Groot 2011) Hiskens and Gong (2006) propose the use of demand response as a tool for load curtailment, while the Smart Grid Task Force (2015) recognize frequency control, congestion management and avoiding grid losses as the potential advantages of demand response for the TSO. While adopting demand response might solve some problems regarding the TSOs challenges, adopting demand response merely as a tool for the TSO, without including it in the electricity trading, would prevent it from having an effect on the electricity markets' efficiency. In other words, the system security would enhance, but the price or demand spikes would not be avoided.

Distributors, or *distribution system operators* (DSOs) are responsible for maintaining the distribution network, which is connected to the transmission network through various substations. Similarly to the TSO, DSOs can benefit from demand response using it for demand curtailment to avoid congestion in their network. (Nguyen, Negnevitsky and de Groot 2011) Applying demand response can also help the DSO by reducing the network investments, as demonstrated by Strbac (2008). In the Nordic countries the DSOs are obliged to act as a neutral market facilitator (NordREG 2009). This means that they have to deliver the same service to all stakeholders without discrimination.

Small consumers, such as for example a household, purchase electricity from the retailer. The electricity is distributed to the consumers using a connection from the local distribution company. Traditionally, the role of the small customer has been very low and limited to merely selecting the supplier of electricity among the available options. (Kirschen and Strbac 2008) On the other hand, harnessing large amounts of households for demand response would provide major advantages in peak shaving as estimated by Hans Gils (2014) in his assessment of the demand response potential in Europe. From the small consumers' perspective demand response might not be considered very lucrative, compared to the current low retail prices of electricity (NordPoolSpot 2015b). The payoff for any task or action conducted by the small consumer themselves would most probably be considered redundant. On the other hand, any financial gains would most probably be considered beneficial if the response of the small consumers was conducted by a third party or the retailer, and the effect of this response to the consumer themselves was minimal.

Large consumers differ from the small consumers in more ways than merely in the demand of electricity. As a contrast, they often have a more active role in the electricity markets, purchasing their electricity directly from the wholesale markets in order to avoid excessive costs created by the retailer as an irrelevant intermediary. The large consumers are also an appealing facet for demand response, because of the large amount of electricity demanded by these major end-users. Some of these actors have an agreement with the ISO to control and direct their loads in order to control the transmission system. (Kirschen and Strbac 2008) This flexibility does not however fall under the umbrella of demand response, as it is used mainly as a system resource to handle unexpected situations in instead of truly incorporating the flexibility in the markets.

Each electricity market participant and network operator has to have one *open supplier*, which has the responsibility for the electricity balancing over the market player in question. The market players form a chain of open deliveries, where the last open supplier is the TSO, and the second to last is the *balance responsible party* (BRP). The Finnish transmission system operator Fingrid (2015) defines the BRP as an electricity market party, which has a valid balance service agreement with the TSO. BRP, as well as other open suppliers have balance responsibility for the power production and purchases to match the consumption and sales of electricity for each hour as described in Chapter 2.1.3. (Fingrid 2015) The European Commission's Smart Grid Task Force (2015) recognizes BRPs as the key users of flexibility, because demand response enables accurate adjusting the electricity balance on a shorter timescale. Currently the majority of flexibility is achieved using flexibility contracts with power plants such as gas-fired plants or hydro plants. In addition, the increase in uncontrollable photovoltaic and wind power production accent the need for the BRP to meet the balancing requirements. (Smart Grid Task Force 2015)

Aggregators are new actors operating in the electricity markets. They operate as brokers between the end users of electricity and the service operators such as the retailer, or alternatively they act as an independent actor sourcing and offering flexibility to the markets. Aggregating offers the opportunity to maximize the potential of flexibility of the grid users. It is a commercial function of pooling de-centralized generation or consumption to provide services within the grid system (Smart Grid Task Force 2015). The aggregators have control over the electricity users' consumption and thus are capable of performing demand response. The mode of operation according to Energy Pool (2015), a current European demand response aggregator in operation, is paying a fixed rate per available MWs of capacity made available and a variable rate for each MWh of consumption that has been shifted by switching off energy-intensive appliances such as heating or air-conditioning for a short period of time. The aggregator represents a large amount of demand, which makes it more efficient to negotiate efficiently on behalf of the end users. Currently the role of the aggregators in the Nordic electricity markets is low, but the significance of having aggregators is however recognized to be very important concerning demand response. The role of the aggregators in the markets is analyzed further in Chapter 3.1.2.

2.1.5 Conflicting Interests among Individual Parties and the Net Benefits of Demand Response

As introduced in the previous chapter, there is a wide range of different parties operating in the electricity markets. These parties have varying roles ranging from nationwide responsibilities such as the operation of the transmission network to single operators merely pursuing financial benefit. It should be understood that these aspirations guide the actions of each market participant, and the action might have influence on the others. It is hence the regulators' and legislative authorities' responsibility to ensure fair and functional market conduct rules before initiating the demand response schemes on a larger scale.

Depending on the market model adopted for demand response, we might face a situation, where we have an aggregation service provider, which has to be able to operate separately from the supplier of the consumers' supplier or BRP. There might be need for information flows between the actors, even though at the same time, these parties might be competitors for each other. (SEDC 2015a) (Smart Grid Task Force 2015) What this means is that we might be facing a situation, in which we have to design some kind of cooperation or data exchange methods between competitors in order to reach competition between the parties and hence achieve an optimal outcome. In addition, if we are to enable independent third party aggregation, each reduced megawatt-hour will decrease the supplier's revenue correspondingly. A more thorough analysis of the market model challenges can be found in Chapter 3.1.2

It should also be understood that each of the independent parties on the demand response markets aim only at optimizing the situation for their part. For instance, a retailer aiming at maximizing its profit through flexibility activities might have an adverse impact on the TSO or the distribution network. For this reason, any partial optimization conducted only one of the market participants in mind is likely to create sub-optimal solutions technically, financially and socially. (Nguyen, Negnevitsky and de Groot 2011)

From the economic perspective, any partial approach is inefficient, and calculating the social benefits of demand response can be expected to be difficult. The social net benefit can however be expected to be more important than the individual benefits due to its nature of indicating the usefulness of demand response for all of the stakeholders. In addition, assessing the net benefits removes the risk of conducting flexibility activities, which have negative net effects, which otherwise might occur. (Nguyen, Negnevitsky and de Groot 2011) (Nguyen and Negnevitsky 2012) From a regulators' perspective this means that the market layout should be designed concerning the net benefits, disregarding any considerations concentrating only on one actor. More specific analysis of the net benefits as well as a model for estimating the profitability of a single bid can be found in Chapter 3.1.1.

3 Research and Analysis

3.1 *Regulatory and Market Models for Demand Response*

Although demand response is a relatively new scheme, there are already some markets, where the end-users can bid their demand reduction on an open market. This chapter concentrates on assessing the variant modes of operation and the optimal choices for the Nordic markets. The chapter addresses the proper level of compensation for demand response in light of the market experiences as well as relevant studies regarding the economic evaluation and net benefits. Special attention is put on addressing the dispute regarding the correct level of compensation due to the external costs inflicted on third parties. The section concludes by offering a method for determining the measurement and verification of demand response to be used in the Nordic electricity markets.

3.1.1 Pricing and Valuation of Demand Response

As reported in the previous chapters, there are multiple functional markets for demand response at the moment. Regardless of the experience we have had in this new market player during the years of operation, there is still some disagreement regarding the proper compensation for reducing demand. There are differing opinions both in the American, as well as in European markets on how to valuate demand response and how to divide the profits among the market participants. An intrinsic stance might be to simply pay for the response according to the current market price, but there are arguments for decreasing this monetary compensation for the flexibility. In this chapter the study presents the variant stands and their reasoning.

The American markets have had the role of a pioneer in demand response services. For this reason the first regulatory stand regarding the value of demand response was set by The Federal Energy Regulation Commission (FERC), as they introduced Order No. 745, Demand Response Compensation in Organized Wholesale Energy Markets. According to this, demand response resources should be compensated at the locational marginal price (LMP), provided that the LMP was at a sufficiently high level according to a net benefit test. It was also decided that the resources participating in demand response must be resources, which are unexposed to the real time price of electricity. (FERC 2011) This ruling has set the nationwide standard for the appropriate valuation of demand response. The electricity markets in the USA have a nodal pricing system, where the price at each LMP takes into account both the current scarcity of generation as well as the transmission capacity. Thus compensation based on LMP reflects the value of demand response to the system in terms of electricity balancing and transmission congestion management. (ACER 2014) What this means, is that according to this statement and disregarding the few restrictions to participating in demand response programs, demand response should be valued at the same level as electricity. This should in fact be the natural outcome in the markets, provided that the market is designed so that it does not have unfavorable effects and flexibility resources can participate on a level field compared to other sources of electricity. It should not make a difference, whether the additional energy to be purchased comes from increasing production at power plants, or reduction in the consumption just as long as the price can be determined in the markets and the increase in capacity verified.

Regardless of FERC’s definition of demand response policy, there has been a strenuous debate regarding the proper level of compensation for demand response. According to the opposing view against paying the full market price for demand response, paying the full market price for demand response results in a compensation, which exceeds the value of the response. (Hogan, Implications for Consumers of the NOPR's Proposal to Pay the LMP for All Demand Response 2010) This opposing argument is based on the idea that while a demand response participant is paid the full market price, it is at the same time avoiding the payment of the marginal cost of generation in the retail tariffs. As a result, the price paid for the reduced consumption likely exceeds the cost of using wholesale market generators to produce this energy and we are facing an efficiency loss. As a solution to this problem, it is suggested that the compensation for demand response should be defined by subtracting the retail tariffs from the market price. This subtraction is denoted as LMP-G (R. Borlick 2011) In short, this economic debate concerns the long-term benefits and the possible distortions caused by unsuccessful pricing regulations.

Decreasing the price paid for demand response might prove to be problematic at least in the Nordic electricity markets concerning the adoption of flexibility. At the moment, the electricity prices can are very low, and the consequent loss of profit margin by paying even lower than the retail price of electricity would most probably decrease the amount of demand response to a minimum (NordPoolSpot 2015a) (Falk and Rosenzweig, Critique Betrays Misperception of Purpose of Demand Response 2011). This might also be against the idea of accepting demand response as an equal resource on a level playing field in the electricity markets as suggested by the European Commission (Smart Grid Task Force 2015). Regardless of this, it should be understood that the pricing decision should not be based on the expected increase or decrease in demand response services. The argumentation should instead be based on economic evaluation and net benefits on the long run. It is also arguable, that the relevance of the LMP-G argument is low as long as the price is determined on open markets according to current demand conditions as described in Chapter 2.1.1. In order to establish an understanding regarding demand response and its value in the markets, one should however assess the question more thoroughly.

The introduced views on the rationale behind the LMP-G argumentation are however challenged, expressing some putative errors. The shortcomings of the logic are disclosed by comparing the argument to a situation, where fuel tax is imposed on some generators of energy while others don’t have to pay it for instance due to their minor emissions. By following the LMP-G logic, we should also decrease the price we pay for the less polluting producers by the amount of tax paid by the other producers. Otherwise the tax would put an efficiency wedge between those who must pay the tax and those who are exempt. The LMP-G argumentation is rationalized as leveling the playing field, but in light of this the whole concept seems to be somewhat distorted. Even though the price difference can be considered as an example of operating cost inefficiency in the electricity markets, there is a strong argument for allowing the markets to operate in this fashion. Leveling the prices would render useless all the public purposes, for which the tax was set in the first place for one reason or another. In addition to this, the market price (in this case locational market price, LMP) reflects the current market situation and should be taken as given for each of the market participants. The same analogy should be true also in the case of demand response. (Falk and Rosenzweig, Critique Betrays Misperception of Purpose of Demand Response 2011) (Falk, We Agree on Everything, Except Compencation at LMP 2011) This means that the market price is considered as the correct level of compensation for the specific amount of electrical capacity. A level playing field refers to allowing access for new participants to bid and compete against each other. It does not mean that we should compensate every electricity production method according to the level of their production expenses. In light of the argumentation above, the ideas about leveling the costs as a result of market price seem to be somewhat misshapen.

Even though the opinion of paying less than the market price for demand response resources seems biased, there might be some veritability to the LMP-G arguments. There are some questions regarding considering demand response equally compared to generation, and some arguments have stated that regardless of similar features they are not the same physically or economically. This intuitively simple transaction proves to be a bit more complicated, as explained in the comments for FERC demand response proposals (Hogan, Providing Incentives for Efficient Demand Response 2009). To understand this view, one must see, how the whole reason for having specific demand response programs is actually a result of retail rate structures intervening with the market. The resulting demand curve is considered inadequate in depicting demand conditions. Due to the market model, there is also lack of interest in reducing consumption when the prices are high, because of the retail tariff. This could be avoided by having real-time pricing for all customers, much like the wholesale markets. The solution regarding demand response should not be paying market price for demand response. Instead, the solution should be to charge a hourly market price for the actual consumption and have no other demand response at all (Hogan, Demand Response Compensation, Net Benefits and Cost Allocation: Preliminary Comments 2010). This however is not the case, at least for now, in the retail electricity markets, and the appropriate demand response compensation remains a question. It would seem that we are facing a situation, where we are applying complex structures to compensate for an error in the markets since there is no will to correct the actual market error. This is naturally bound to make it increasingly difficult to estimate the net benefits.

In the case of dynamic pricing, the consumers pay according to real-time or day-ahead pricing for the usage of electricity. Faced with this kind of pricing, any customer is able to make a contract for a fixed price to purchase a given quantity of electricity. After this, it is evident that the customer now owns the energy, and is free to consume it or sell it back to the retailer or a third party. According to Hogan, should this customer sell this electricity back, the appropriate price paid for it would be the market clearing price during that time. By remembering that the customer had already paid the fixed price, so the net transaction for the customer would be *market price minus the fixed price,* ergo the value of demand response should be less than the market price. Hogan continues by explaining how this transaction would likely be described simply as resale of power, but from the system operator’s perspective the power flow in these transactions is indistinguishable from demand response. By applying the symmetry principle, the payment for the transaction through purchase and sale should be the same as in demand response. (Hogan, Providing Incentives for Efficient Demand Response 2009) (Hogan, Demand Response Compensation, Net Benefits and Cost Allocation: Preliminary Comments 2010) This is a strong argument favoring the LMP-G logic. The argumentation proceeds by stating, that while many statements regarding demand response take for granted that reducing electricity prices is beneficial and a cost-effective ambition, this assumption might be wrong. The expected reduction in electricity prices as a result of consumer flexibility by paying the full market price can be considered as a transfer payment from generators to customers. It is of course considered beneficial for the customers, but from the perspective of generators it is a cost, and the total sum effect at least according to Hogan remains non-existent meaning that there is no net benefit at all. He argues, that the benefits of demand response amount to no less than “an application of regulatory authority to enforce a buyer’s cartel”, and paying full market price for the flexibility would be an unfair compensation and therefore should be also considered as market manipulation (Hogan, Implications for Consumers of the NOPR's Proposal to Pay the LMP for All Demand Response 2010). (Hogan, Providing Incentives for Efficient Demand Response 2009) The proponents of paying the full market price however bring up the important notion that the whole reason for having such a debate was originally raised in the context that the markets were not attracting a sufficient level of demand response under the previous pricing scheme, which valuated demand response below the market price. In addition, it is noted that the LMP-G proponents seem to disregard the high cost of adding capacity and the cost of outages in their argumentation. (Falk and Rosenzweig, Critique Betrays Misperception of Purpose of Demand Response 2011)

This debate is closely linked to the dispute about whether the flexibility provider should even be allowed to sell its flexibility and at which price? The fundamental issue centers on the difference between reselling something you have purchased and selling something you would have purchased, without actually purchasing it as often argumented in the case of demand response. The FERC order No. 745, introducing demand response compensation and implementation in the USA includes a comment stating that demand response should be treated in all essentials equivalent to supply response, and that it should be rewarded with the same market clearing price as any other kind of response (FERC 2011). A similar definition can also be found in the European Commission’s EG3 report stating: “The value of a MW should be decided regardless of who or what is providing that MW” (Smart Grid Task Force 2015). It should be understood that what is being sold in demand response is <u>not the power</u> someone else has bought, but instead the <u>ability to consume</u> as much power as one likes at the retail rate. This can be demonstrated by an analogy with the stock markets. If one holds an option to buy one share for $100, when the current price for this share is $130, $30 is an underestimate of the value. Further, as the volatility rises, so does the value of this option until it is $130 irrespective of other factors. The value of this option depends on multiple factors: time value of money, time until expiration of this option and the volatility - and so also should the price of an opportunity to consume electricity. This aspect is however overlooked in the arguments favoring LMP-G pricing. In addition to this logic, it is also possible that the LMP actually is an underestimate of the value of possible lost load during outages. (Falk, Paying for Demand-Side response at the Wholesale Level 2010)

There are valid arguments for both views on the appropriate valuation of demand response in day-ahead markets, and some of the main arguments are acknowledged even by the opposing side (Falk and Rosenzweig, Critique Betrays Misperception of Purpose of Demand Response 2011). The formal correctness of the LMP-G argument is recognized despite supporting FERC’s decision of remunerating demand response for full LMP. The key points of LMP-G argument are described to be valid, especially in the case when G is only slightly less than LMP. At the same time, there is a wide range of inefficiencies in the market, and demand response is likely to be under-rewarded for the various services it provides. (Falk, Paying for Demand-Side response at the Wholesale Level 2010) (ACER 2014). There are many benefits for adopting demand response as reported in several high level reports (ACER 2014) (International Energy Agency 2011) (Smart Grid

Task Force 2015). The market structure design should be the result of careful comprehensive assessment instead of putative benefits. For these reasons, it would seem that the LMP-G approach at pricing is suboptimal from a wider perspective and we should pay the full market price for demand response. After examining these largely distinct opinions on proper valuation of demand response, it should be understood that the issue has a significant political account in addition besides the quantitative or economic factors. As described above, the European Commission's view favors paying the full market price for demand response similarly to FERC's decision on the North-American markets. At the same time, the current suppliers of electricity can be expected to object this ruling, since it can possibly decrease their profits. On the other hand, the experience so far has shown that we are unlikely to reach the desired levels of demand response without paying full market price for this resource. In the end, it is possible that we have to sacrifice part of one market player's benefits in order to obtain the optimal outcome. The decision is left to be resolved by the legislators, and further studies regarding the most beneficial solution will be needed.

As a response for the possible imperfections regarding demand response pricing, it is also suggested to conduct a net benefits test to mitigate market interference since "a poorly designed demand response compensation system could do more harm than good" (Hogan, Demand Response Compensation, Net Benefits and Cost Allocation: Preliminary Comments 2010). Similar arguments can also be found in some other publications (R. L. Borlick 2010) (Chao 2010). Regardless of the view on the value of demand response, there seems to be a common understanding of considering the net benefits before taking any specific action in implementing demand response. According to FERC's ruling, the accepted day-ahead demand response programs have to pass a net benefits test, which determines that the compensation at full LMP is available only, when the LMP is sufficiently high to guarantee that the benefits exceed the costs. The correct level of LMP to ensure net benefits is calculated each month and informed to the participants before bidding. (FERC 2011) (FERC 2015)

Regardless of FERC's decision to estimate the net benefits of offering demand response, there is some question regarding the validity of such calculations on a larger scale. Calculating the benefits of demand response is a very challenging task, and often performed at too narrow perspective, concentrating too little on the financial value delivered to the power system as a whole (U.S. Department of Energy 2006). In addition, there has been lack of a comprehensive method for estimating the total effects regardless of the market setting across all players while most studies have concentrated on estimating the individual benefits only for few of the many stakeholders (Su and Kirschen 2009) (Kah-Hoe and G.B. 1998) (Parvania and Firuzabad, Demand Response Scheduling by Stochastic SCUC 2010). (Nguyen and Negnevitsky 2012) It would seem that there is a call for more specific elaboration of the idea of estimating the total benefits of demand response as introduced by FERC.

Without a proper assessment of the demand response bids and their effect, there is a risk of it being disadvantageous at the larger level. The decision to dispatch demand response should reflect the value it can provide for the system. In this case, discovering the value is however complicated due to the nature of the scheme and requires specific assessment. There is however a model available, which takes into account the whole scheme instead of concentrating on only some of the participants. This assessment framework aims at recognizing and calculating the net benefits for the system a whole. Due to the different possible modes of operation for demand response ranging from the TSO-enabled services to market-based retail-models, there have to multiple different calculation methods, which are adapted to be suitable for each of these models. The model is designed so that one can elaborate the basic framework according to the requirements set by the market conditions or model. (Nguyen and Negnevitsky 2012) Due to the scope of the study and the selected market model, a look is taken especially at the retailer-based model, which is suitable also for the market models described in Chapter 3.1.2.

The main idea of the assessment framework is based on having a two-step cost/benefit analysis. These steps are in-market and out-market. The in-market deals with parties, which are participating in the demand response market such as the aggregator or supplier, while the out-market estimates the benefits of parties, which are not in direct involvement with the market such as the TSO or generators in the case of this study. It should be understood that the same framework can be modified to assess the benefits under all the various different demand response schemes by exchanging the roles for the in-market or out-market calculations to match the desired market model. The additional benefits occurring to the out-market parties are considered to be free, since the parties enjoy the benefits without actually paying for them. The analysis is performed during a time period, T, which coincides with the generation dispatch interval in the markets. Within this period, the analysis is performed for both of the steps. The framework assesses the social surplus based on the two steps, after which a decision is made, whether the cleared demand response is dispatched at all. Disregarding demand response bids, which are unable to provide a net benefit on a large scale is extremely important because without a proper evaluation the full potential of the schemes cannot be reached. In addition, the overall efficiency of the markets can be threatened without limiting the counterproductive demand response offers. (Negnevitsky, Nguyen and De Groot 2010) (Nguyen, Negnevitsky and de Groot 2011) (Nguyen and Negnevitsky 2012) A flow chart of the framework is presented in **Figure 13**.

The calculations in the both of the steps is based on cost/benefit analysis (Mishan and Quah 2007) (Nguyen and Negnevitsky 2012). The market analysis method is formed using a specified mathematical function for each of the market participants. This function represents the market conditions, and by combining these independent functions we can assess the big picture ergo total benefit. The input data for these calculations consisting of retail prices, generation costs and failure rates etc. can be obtained from the markets and the market operators,. It has been recognized that the calculations required for such assessments can be time consuming and complex, and the scientific studies have had no limitations regarding simulation time or trial amount in their computational analyses. In real market situations however, the efficiency of these calculations should be taken into account so that the methods are really applicable in their intended uses. It was discovered that the time required for calculating the market clearing model was small using GAMS –programming. This is a result of the demand and supply curves being linear and thus having convex and quadratic forms, which can be solved with relatively low effort. (Nguyen and Negnevitsky 2012)

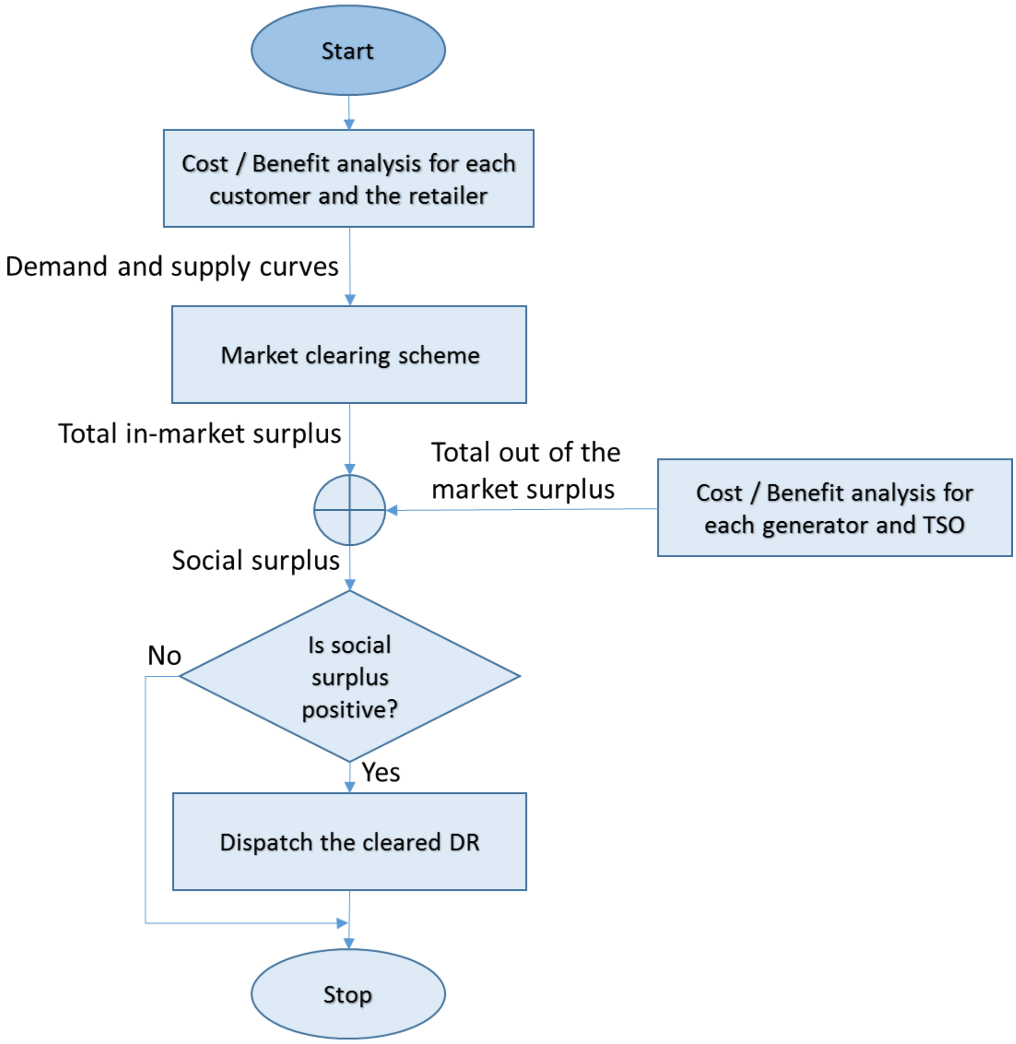

Figure 13. *Flow chart of the framework for comprehensive evaluation of demand response resources according to the retailer-based model. An elaboration of (Nguyen and Negnevitsky 2012)*

The framework illustrated in **Figure 13** presents a framework, which is capable for assessing the total financial benefits for demand response. Due to the adaptability of the model in multiple different scenarios, and the focus on reaching optimal net benefits, it seems that having a model like this is essential in creating a functional demand response market, which in turn would be able to provide all the potential expected benefits. The functionality of this model appears to be evident, and it would seem plausible to use it as the basis in the future development of the demand response valuation schemes.

The functionality of the model however does not take into account the costs that would incur in creating such a framework to be constantly in use in the markets. Applying new structures can be expected to cause expenses, and thus also face opposition. The development of these measures is likely to cause expenses, which in the end would be paid by the market participants in the form of increased payments. While it is understandable that there is no major willingness to create additional structures causing expenses, it should be emphasized that there is a high level understanding of the need to introduce flexibility resources in the markets (ACER 2014) (Smart Grid Task Force 2015). For this reason, the situation should be considered on a longer timescale. Any alteration in the current scheme will cause expenses, and having demand response required some additional layers of complexity. If we were to introduce flexibility without fulfilling the requirements, we risk ending up in a situation, where some individual market participants gain profits, but the system as a whole has a negative impact on the markets. Based on this argumentation, creating a system to evaluate the net benefits of demand response would seem to be required. In any case, the schemes should be designed to operate without excessive workforce and special attention should be given to minimizing the expenses in applying and design of these structures.

3.1.2 Market Models for Demand Response

The electricity market conduct rules are a result of the liberalization of the markets as described in Chapter 2.1.3. It is evident that these rules were created in an era, when demand response was not considered thoroughly as a resource. Because of this, the current market rules might need to be revised in order to sufficiently enable demand response programs' operation. According to the current legislation, demand response can in fact be provided, but only by the current suppliers, thus removing the possibility of having a third party aggregator. (The Finnish Government 2013) Before revising the market rules, there should however be an understanding of the desired outcome. A market model refers to the agreed policies and procedures between the market players according to which the different compensations, data and electricity flows are directed. The aim of this chapter is to take a look at the different models and their effects on the markets. The models and their functions are then reflected against the Nordic market features as well as the basic principles of electricity market design in order to find the optimal solution. It should be also noted that while the contents of this chapter bear close resemblance and are linked to the convictions presented earlier, they are two different subjects. The research concerning valuation examined in Chapter 3.1.1 is an economic analysis of the effects regarding how demand response is valued in the markets. This chapter instead concentrates on the transactions or compensations between the market parties regardless of the valuation of demand response on the market. Due to the similarities between these two aspects, the situation is likely to create confusion and thus has to be emphasized.

The most prominent issue in designing the market model is the problem regarding the effect demand response might have on the balance responsible party, when the demand response is organized partially or completely by a third party such as an independent aggregator. This issue is recognized by a diverse group of stakeholders (Eurelectric 2014) (ACER 2014) (Finnish Energy Industries 2014). At the same time, there are substantial benefits to be made by allowing third party aggregation to participate. In addition, introducing such a novel market instrument is likely to require resources, which can be achieved by pooling the demand as in the aggregated solutions. (Makkonen and Lahdelma 1999) (ACER 2015) (Smart Grid Task Force 2015) The issue is a result of overlapping responsibilities regarding the balancing of the end-user of electricity. When a customer agrees to a contract with a third party aggregator, this third party gets an implicit access to the organized electricity markets on behalf of this customer. By the mandate given by this agreement, the aggregator is allowed to bid the value of the consumer's consumption flexibility or injection to the markets. Within these markets, this injection of electricity or shifted consumption is treated as MWh of energy. The problem lies in the fact that at the same time, the customer has a supplier, often also having the role of a balance responsible party. (Smart Grid Task Force 2015)

The supplier is required to source an amount of electricity in the day-ahead market, which is equal to the expected consumption of its consumer as explained in Chapter 2.1.4. As a result of this, the power balance is maintained. However, should the aggregator have offered a flexibility bid to the market which is then cleared and put into effect, the level of consumption changes according to the bid. As a result of this, the balance responsible party (the supplier) will not receive payment for the electricity it sourced on the market beforehand. What this means is that the supplier has a changed energy position and is left in a situation, where it has sourced electricity in order to fulfill the regulated duties and which it now is unable to sell. In addition to this, the action taken by the aggregator causes a change in the consumption, which in turn creates imbalance in the balancing portfolio. This imbalance is compensated as a monetary transaction by the balance responsible party, even though the the imbalance would be caused by the aggregator. (SEDC 2015c) (Smart Grid Task Force 2015) As it is, the market rules would "de facto" allow a systematic method for the aggregator to profit by causing expenses to a separate market player. Following this reasoning, is clear that this is an issue to be solved by market design or regulatory action before implementing demand response at a wider scale. The challenge is in designing fair rules, which both remove unfair costs and at the same time allow lucrative participation for demand response programs. As described in the previous chapters, there have been some issues regarding the small level of participation for demand response due to unnecessarily low compensation. This emphasizes the need for creating a simple method without complicating the system too much. There are a few different solutions available for this inherent problem in the design of balance responsibility in the Nordic electricity markets. A look will now be taken at these options to assess their applicability as well as benefits and disadvantages. Each of these models is analyzed based on the suitability for the Nordic markets, and the market model is presented in an illustration highlighting the relations between the market players. Since there are various and partially overlapping market and compensation models, the variant options and their rationale are summarized in **Figure 16**.

The first option would be to simply oblige the customer to sell the flexibility only to his own retailer (Eurelectric 2014) (Eurelectric 2015). This simplest market model nominated as the *Cooperation* model, and it is presented in **Figure 14**. In practice this means, that the supplier or BRP has to assume the role of the aggregator or alternatively to work in close cooperation with it. By forcing the demand response transactions to only take place between the current supplier, there is no possibility for unfair costs to occur. The model is based on the supplier assuming the role of the aggregator. Instead of merely sourcing the electricity according to the estimated level of demand, the supplier in this model would continuously assess the cost-efficiency of sourcing the electricity or activating demand response within the end-user portfolio. In addition to this model, the same model allows operating using a hybrid model, which incorporates features from more complicated schemes while still fitting in the basic model. This means that the aggregator could also assume the role of a consultant or a technical facilitator by selling the services to the supplier. (Eurelectric 2015)

The basic model does not incorporate aggregators bidding on the markets on behalf of the customer, the inclusion of third parties is however possible, just as long as the requirements of this model are met. There is a bit more advanced market model based on this method created by the Universal Smart Energy Framework (USEF), which is an organization created by several energy companies. This hybrid model consists of several different data flows as well as defining the roles and responsibilities for each party, but the main idea is simple. The supplier and the aggregator work together and sign a contract for an aggregator to provide services. This contract includes the operating conditions, under which the aggregator acts under the flag of the supplier. This means, that even though there was an aggregator, it is considered as a subcontractor of the supplier instead of a third separate party. Under this USEF model, the optimization of the portfolio is conducted in cooperation between the aggregator and supplier to find the lowest operational costs. (USEF 2015)

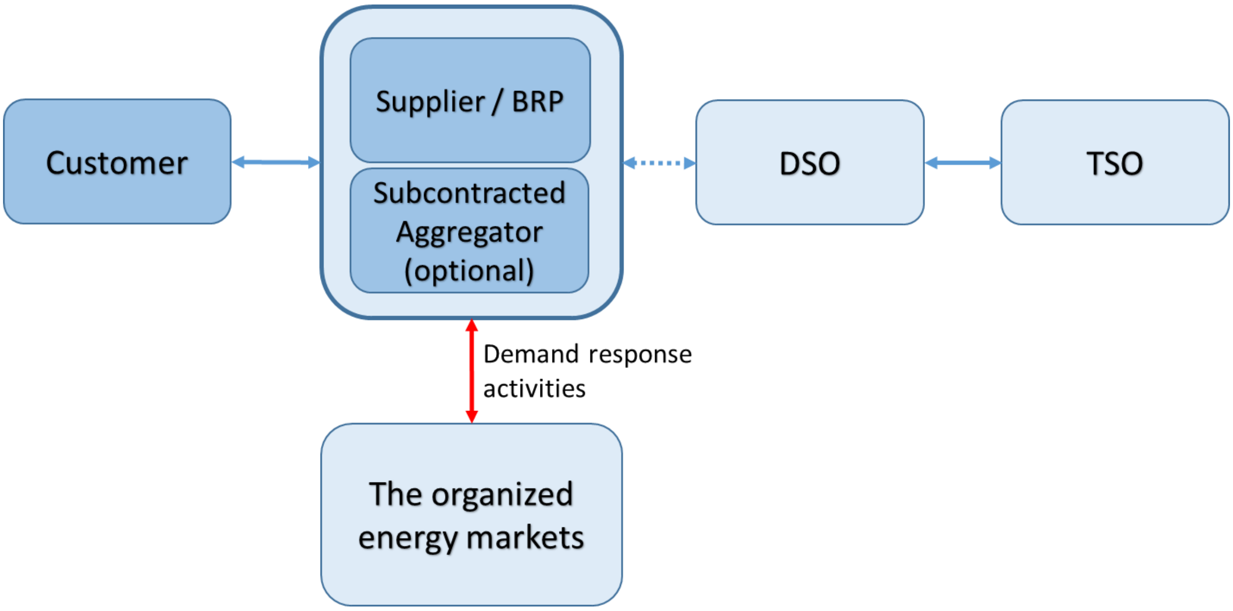

Figure 14. Demand response market model, where the supplier or BRP takes the role of the aggregator or operates in cooperation with it.

The main benefit of this simplest model of limiting the demand response activities to the own supplier is that the chain of balance responsibility remains intact. Regardless of participating in demand response activities, the customer has only one contact point, and no additional costs occur due to the possible demand response actions. The supplier or BRP, or alternatively the consortium of supplier and aggregator estimate the demand according to the customers' needs, market situation and available flexibility, resulting in precise balancing. The only market model based potential impact in need of special management would be the link between the supplier and the DSO, which is symbolized using the dashed arrow in **Figure 14** (Eurelectric 2015). The demand response activities have an effect in the distribution network, which has to adapt to the changes caused by demand response activation. The effect of this impact can however be expected to be minor at least in this simplest market model. Even without demand response activities, the supplier has to operate within the limitations of the network, and since the demand response activities are organized by one single consortium, the estimated demand level is likely to be accurate. In some inefficient or undeveloped networks, there however might still be congestions limiting the participation for demand response. A more detailed analysis of the network requirements can be found in this chapter after discussing the various market models.

Examining the model raises a question of the efficiency of operating the demand response markets. If we adopt a model, where the aggregator and supplier have to operate as a single entity, do we limit the development of new aggregators or aggregating services? (ACER 2015) There are several high level studies, which emphasize the need to accept diverse flexibility resources and versatile actors in the upcoming demand response markets. Allowing consumers to offer their flexibility using any possible means is also encouraged. The Smart Grid Task Force states: “All aggregation service providers must be able to compete on a level playing field: aggregated load should be legal, facilitated and enabled in all markets. Aggregators and suppliers should have the same ability to extract the value of flexibility services on behalf of their consumers.” (ACER 2014) (Smart Grid Task Force 2015) (CEER 2014) As discussed in Chapter 2.1, competition and rival parties in the markets encourage the efficiency. New entrant aggregators are in fact allowed to assume the role of a BRP or supplier and hence are allowed to operate in the markets. Should a new entrant aggregator be willing to assume the role of both supplier and aggregator, it is required to fulfil a list of specific requirements specified in the electricity market act (The Finnish Government 2009). After being accepted as a BRP, the new market player would be allowed to operate as the supplier and aggregator. The question remains whatsoever, whether the requirements still cause an unnecessarily high barrier regarding the entrance of new market participants. These requirements consist of technical facilities to manage the responsibilities of the task. In the developed Nordic markets, where smart metering and dynamic pricing is already available, the barrier of assuming the role of a BRP can be considered to be relatively low (Eurelectric 2015) (NordREG 2014).

The second model incorporates a *separate third party aggregator, which is operating independently*. The aggregator is in direct contact with the customer, and performs demand response activities on the electricity markets. The aggregator is allowed to operate independently without consent or agreement of the supplier and can be considered to act as a service provider for the customer, which has an impact on the BRP’s balance as described above. (Eurelectric 2015) (Smart Grid Task Force 2015) In order to engage in market activities according to the second model, there have to be precise rules for the interaction between these actors. The second market model is presented in **Figure 15**. There are multiple different solutions for the intrinsic problems of allowing a third party aggregator to operate in the markets. The study will now take a look at these options and assess their applicability for the Nordic electricity markets.

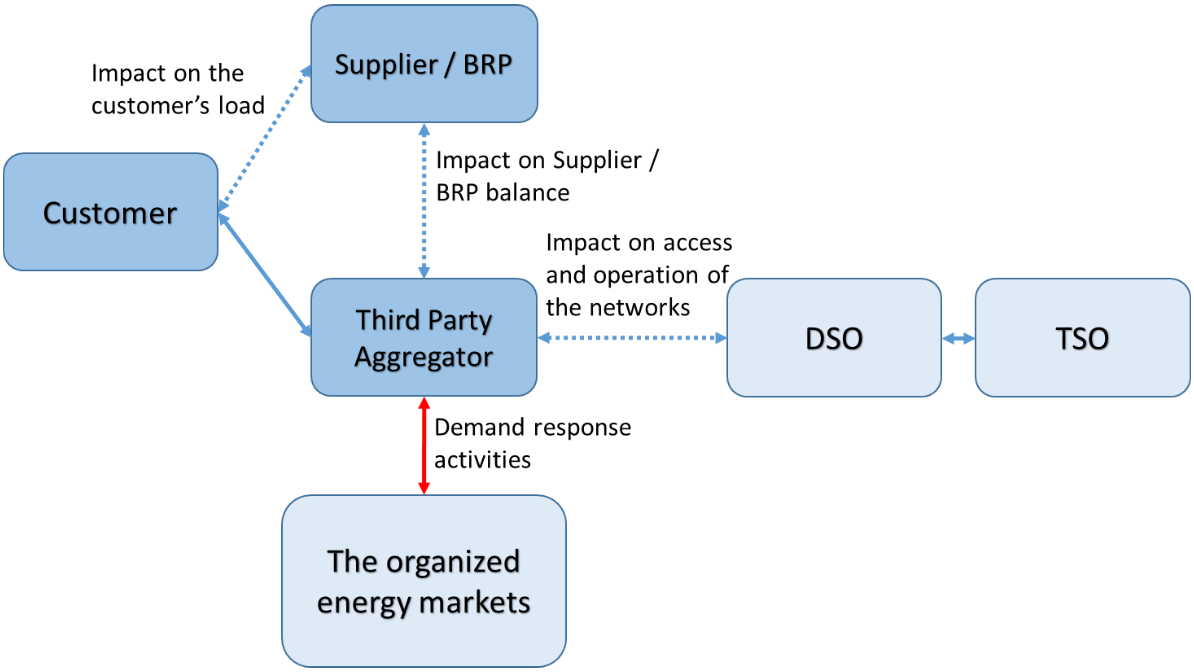

Figure 15. Demand response market model, where the aggregator is an independent third party, visualizing the impact a third party aggregator has on different parties.

There are a couple of different options on how to compensate the supplier for the negative consequences of demand response, which can be divided into two main categories:

1. The first option is nominated as *the imbalance compensation model.* It is based on an idea, in which the BRP or supplier imbalance is not neutralized, but instead the imbalance is compensated by the aggregator at the imbalance price through the TSO. In addition, the BRP would not be penalized for imbalances, which support the system requirements. (Eurelectric 2015) From the BRP's point of view this model increases the risks of operation, since their compensation in this model depends on the imbalance price. Should the sourcing costs exceed the imbalance compensation, the demand response event would create operating losses for the BRP/supplier. Even more alarming in this model is the fact that operating according to the imbalance compensation model would allow the third party to cause these additional costs at any given time regardless of the supplier's consent or market situation. Having this kind of power over another market participant is likely to cause imperfect competition leading to a total welfare loss. (Wangesteen 2005) Regardless of these possible market failures inherent to this model, it would seem that operating according to this model is possible, provided that the actions are limited to the balancing markets only. However, the fact that the model cannot be expanded to include the day-ahead or intraday markets makes it unfavourable to adopt. Adopting the imbalance compensation model would complicate the market by demanding two separate models only to cover the different market segments.

2. The second option is to neutralize the imbalance created by the third party aggregators. The imbalance is neutralized by the TSO, and the BRP or supplier is then compensated for the energy, which is re-routed and sold to the markets by the aggregator. It should be noted that this solution shares resemblance to the discussion in Chapter 3.1.1. In this chapter, the focus is however on determining the possible compensations between market parties regardless of the price in the markets. This option to neutralize the imbalance can be divided further into three different models according to the compensation method: A corrected model, a regulated model and a contractual model. It should be also kept in mind that all market players should operate under the same responsibilities. Consequently, any third party aggregator bidding demand response on the markets should also have balance responsibility. If a customer is unable to deliver the response according to the demand response bid, the aggregator bears the imbalance cost. (Eurelectric 2015) (Smart Grid Task Force 2015) What this means in practice, is that there is a need for one single consumer to divide the balancing responsibility between two different actors: the aggregator and the supplier, or at least create a mechanism which would ensure that no unjust compensations have to be made.

   The corrected model is based on the aggregator refunding the amount of energy that has been "sold" to the aggregator in the form of demand response. The metering data of a customer in this model is corrected by the amount of activated demand response. What this means is that the customers remunerate their own supplier using their contracted rates for the specific amount of energy. The customers in turn are compensated by the aggregator for the demand reduction. (Eurelectric 2015) A more thorough evaluation of the proper compensation value of demand response can be found in Chapter 3.1.1. It is evident that the advantage of this model is its inherent simplicity. The model does not require any additional processes or complicated calculation, and can hence be considered to be relatively transparent and easy to understand. It does however require exact metering for both consumption as well as demand response in order to be transparent and reliable. This should not be an issue in the Nordic markets with a wide coverage of smart metering (NordREG 2014). Eurelectric has stated that applying this model might be difficult for smaller customers (Eurelectric 2015). No issues are however seen in operating according to the corrected model with small-scale electricity-users. Advanced metering and telecommunications enable easy handling of a wide range of users, which is the main idea of aggregation in the first place. Lucrative demand response is often dependent on accessing the reduction potential of multiple end-users, which is why Eurelectric's statement about applying this to small consumers would seem somewhat biased (Parvania, Optimal Demand Response Aggregation in Wholesale Electricity markets 2013) (Smart Grid Task Force 2015).

   The regulated model introduces a slightly firmer regulatory framework on the compensation. The BRP or supplier is compensated by the aggregator at a regulated price level. The compensation price in the model is set by the national regulatory authority at a level, which at minimum would cover the costs of the commodity. (Eurelectric 2015) The model raises a question, whether the design actually inhibits the pricing innovations conducted by the aggregator. Determining the proper compensation price is also likely to be challenging, and demands resources. Should the compensation price be constantly changing, even more resources are used for this action, which in fact could be naturally achieved on open markets without unnecessary expenses. There is also a risk of creating an arbitrage on the markets, since the compensation is not determined strictly by market conditions. An arbitrage refers to a situation, where the simultaneous purchase and sale of an asset allows profit due to the price difference. It occurs naturally due to market inefficiencies, but in this case the design of the market model can be seen as the source of the arbitrary conditions, and distorting the markets. (Luenberger 2013) (Wangesteen 2005) In addition to the problems mentioned, the compensation price might not ensure proper compensation for the supplier, since the compensation price can differ from the contract price of the customer. Regardless of the model's limitations, it is currently in use in the French markets (RTE 2015) (RTE 2014).

The contractual model is founded on the third party aggregator and the BRP or supplier having a common agreement on the level and methods of compensation. Each demand response event is then compensated according to this contract. (Eurelectric 2015)Having these contracts should not limit the customer's right to select their own service provider without consent from the supplier. Designing a contractual model raises also a question of the details of these agreements. European Commission recommends putting in place standard contracts to ensure the functionality of the model as well as the required communication procedures. (Smart Grid Task Force 2015) Standardizing the framework and contracts can be expected to encourage the adoption of demand response during the roll-out phase. Special attention should however be given to designing such contracts, that they allow for various kinds of agreements between the players instead of merely locking the model into a predefined state. Market opportunities are often created as new innovations, which can be inadvertently disqualified when applying unnecessarily strict standards. Should the contractual model be the optimal solution, it is likely that these market specific guidelines be defined by the national regulatory authority, Energiavirasto, or the Nordic regulators' board NordREG. Designing fair and equitable standards poses an important challenge for the regulators.

The drawbacks of the contractual model are associated with the possible excessive market power given to the BRP or supplier. If this model is the only possibility for demand response, the supplier is able to control the levels of compensation, and the third party aggregator would have to either agree with this level, or give up the demand response operations. Another alternative would be to begin acting as a supplier and applying for the balance responsibility status. This however would not fall under this market model anymore, but would be considered as operating under the cooperation model. At the same time the aggregator would be given additional responsibilities and tasks. As described in Chapter 2.1, it should be kept in mind that from a market perspective it is lucrative to have multiple participants to compete. Having competition is likely to streamline the operations leading to efficiency. The situation should also be considered regarding specialization. The reason for having diverse companies interacting with each other is that the companies are specialized to perform a task, in which they are best at producing value. The most efficient outcome can be achieved when each individual player concentrates on the things they do best, and outsourcing those things, which are easier or cheaper to outsource. (Parkin 2014) Let’s take demand response aggregation as an example. If a market player is very efficient at aggregating load and controlling it for instance by having sophisticated software and competitive staff for this thing in particular. At the same time it is possible that the requirements for sourcing electricity and acting as a supplier does not meet with their resources. In this case the optimal outcome could be achieved by the contractual model, where the aggregator is only responsible for what they do best. Regardless of the argumentation, it can also be that the aggregator or even supplier is proficient at handling both tasks. In that case it might be best to have only one actor. Regardless of the situation, forcing the actors to take responsibility of tasks in which they are incompetent will most likely lead to suboptimal end result. This is why having the contractual market model as the only option cannot be recommended.

It is important to understand, that operating demand response on any of the three models based on compensating the energy to the supplier is dependent on a method to verify the amount of energy, which has been “re-routed” as demand response. (Eurelectric 2015) The compensation is determined according to the amount of demand reduction, which highlights the importance of transparent and accurate methods for measuring it. The measurement and verification of demand response is examined in Chapter 3.1.3. Regardless of the model selected, the main idea in all these options is having a financial adjustment mechanism to compensate the losses. The European Commission’s Expert Group regarding flexibility has defined two main principles for applying such financial adjustment methods; Firstly, the adjustment for the energy should always reflect the sourcing costs. Secondly, the adjustment should ensure that risks and costs are directed to the party that causes the risks and costs. The market mechanism should thus ensure that all electricity sourced on the market and consumed by end customers is paid to the actor, who sourced it. At the same time, the unfair costs incurred through fulfilling the balancing requirements should be avoided. (Smart Grid Task Force 2015)

The role of the aggregator in the market model	Supplier / BRP imbalance	Name of the market model	Market model assessment
Supplier / BRP assumes the role of aggregator or works in cooperation	No imbalance due to market design.	Cooperation model	+ Applicable in current policies + No need for complicated regulation + No balancing issues + Only one service provider per customer - Possibly limiting new participants
A separate and independent third party aggregator	Imbalance is compensated by the aggregator at the imbalance price	Imbalance compensation model	- BRP / supplier becomes dependent on the balancing price - Suitable mostly for aggregators operating on balancing markets - Increases the risk of BRP / supplier
	Imbalance is neutralized by TSO and the BRP / supplier is compensated for the re-routed energy. Concurrently, the balancing responsibility has to be partially divided for these two parties.	Corrected model	+ Easy to understand and transparent - Requires exact metering for both consumption as well as demand reduction - Requires alteration in the balancing model
		Regulated model	- Requires a lot of resources - Reduces pricing innovations - Possibility for arbitrage created by regulated pricing - Risk of unfair compensation for BRP / supplier
		Contractual model	+ Standardized contractual framework would enable fast rollout of varying types of DR - The BRP / supplier might have excessive market power - Need for standardized contracts?

Figure 16. *Comparing the various market models for demand response*

After taking a look at the various possible market models, their suitability regarding the Nordic markets should be assessed in order to find the optimal design. There are robust guidelines for creating the market design in order to realize the full potential of demand response described in Chapter 1.2. The market design should ensure a *level playing field* for all actors, a market design, which *is suitable for all markets* and *scalable* for implementing on the large scale (Smart Grid Task Force 2015) (Eurelectric 2015). A level playing field is generally understood as subjecting same market and participation rules for all of the market players. It is important to notice that creating a level playing field does not mean that the market design should necessarily be limited to only one model. It might be beneficial to put in place several possible participation models for demand response, just as long as all of the models are available for any of the market players. By accepting multiple different operating models, we are enabling more participants to take part in the markets, which leads to more efficient operation as described in Chapter 2.1. The participant is able to select the most optimal form of delivering demand response, and the respective market rules for this kind of activities ensure that the possible external costs are compensated. Based on this argumentation, the recommended solution for Nordic markets should consist of a combination of models, allowing the participation of diverse parties, provided that having only one market model does not bring about superior benefits. Special attention should also be given to designing a combination of models, which does not have contradicting and overlapping qualities.

The final recommendation for the market model is formed by first recognizing the most counterproductive or unavailing choices from the basic market models listed in **Figure 16**. The remaining options are then examined regarding their suitability to be applied as alternatives, out of which a market participant could select the most suitable one for their use. It should be kept in mind, that all of these basic models are designed so that they fulfill the requirement of removing the injurious market effects. At this stage, the comparison is made thinking only about the suitability of the model for the participation of diverse demand-response resources.

Let´s first take a closer look at the *regulated model*. Implementing this model in the Nordic electricity markets would mean a major rollback from the modern liberalized system. Despite actually being in use at the moment in France, it is conflicting with the idea of capturing efficiency by market competition. (RTE 2014) (RTE 2015) (Hunt and Shuttleworth 1996) The model can also be interpreted as being against the European Commission's third energy package market reforms, and there is a very clear opposition to having regulated prices of any kind (ACER/CEER 2013) (European Commission 2009). It is hence highly unlikely that an optimal outcome could be achieved by operating by this model. In addition, calculating the supposedly appropriate price levels for demand response would constantly demand a lot of resources for a task, which could be achieved naturally in the markets and most probably with a higher accuracy. In addition, regulating the prices is bound to limit the aggregators' innovations concerning pricing. For these reasons, the regulated model will be disqualified as an option in designing the Nordic demand response market model.

The *imbalance compensation model* is a simple model based on compensating the balancing error for the BRP or supplier. The simplicity of the model might actually not be a benefit in itself, since the whole model can be considered to ignore the drawbacks created by demand response. Using this model, every flexibility event would create balancing error, which is then financially reimbursed. This financial payment does remove the unjust effects for the third party, but it still does not remove the balancing problem. The reason for having balancing and paying for deviations stems from network requirements (Fingrid 2015). Designing a regulatory scheme, which simply ignores the negative effects for the network using a financial compensation would seem to be counterproductive and absurd, especially if there are other alternatives for the market design. From the supplier's or BRP's point of view this model would also pose a major risk, since they would simply have to agree to the compensation level without any possibility of control. This would increase the risk without any kind of a compensation for the BRP. It could also be argued, whether this model even provides a solution to the endogenous problem in demand response of having unfair effects for a third party in the first place. The balancing error is indeed solved, but this solution would in turn create an additional problem regarding risk management while doing so. Due to the deficiencies described above, the imbalance compensation model is also ruled out from the considerations regarding an optimal market model.

How about the *corrected model*. The model is based on compensating the energy losses for the supplier/BRP. This compensation for the energy would be paid by the aggregators according to the amount of sourced but not consumed energy because of demand response. As a result of aggregator purchasing the energy, the balancing error caused by demand response would be corrected. Any additional imbalances would naturally be paid by the supplier/BRP themselves. At the same time the supplier would be paid a fair price for the energy, thus also solving the problem regarding the supplier´s open energy position. Let's examine this transaction more closely. As an example, we assume that the BRP/supplier has purchased a position for 10 MWh of energy in the electricity markets in order to meet the expected demand of its customer base. After this purchase, the aggregator asks its consumers to reduce consumption by 2 MWh, and compensates the BRP/supplier for the energy. This transaction can be interpreted as the aggregator purchasing the energy from the supplier, even though it is in fact created by the consumers' reduction in consumption. This exemplary transaction between the two parties and markets is presented in **Figure 17**. By examining the situation, it is evident that the possibility for an aggregator to make any kind of profitable business is dependent on having two different prices. What this means is that the transactions have to take place in two different markets where the supplier first sources the energy, and secondly the aggregator resells this energy to the markets. What is found important to understand here is the fact that demand response is likely to be able to produce more value as it gets closer to the delivery hour. If there is demand for electricity and a lack of adequate supply, reducing the demand is an easy way to make profit – provided that one has the resources to do so. This is because demand response would not require proactive planning, but could be simply activated by real-time control of the consumers' appliances. The aggregator according to this model is in fact reselling the energy for a better price due to the supplier's inability to steer it to a more profitable end-use, which is bound to increase the efficiency of the system as a whole.

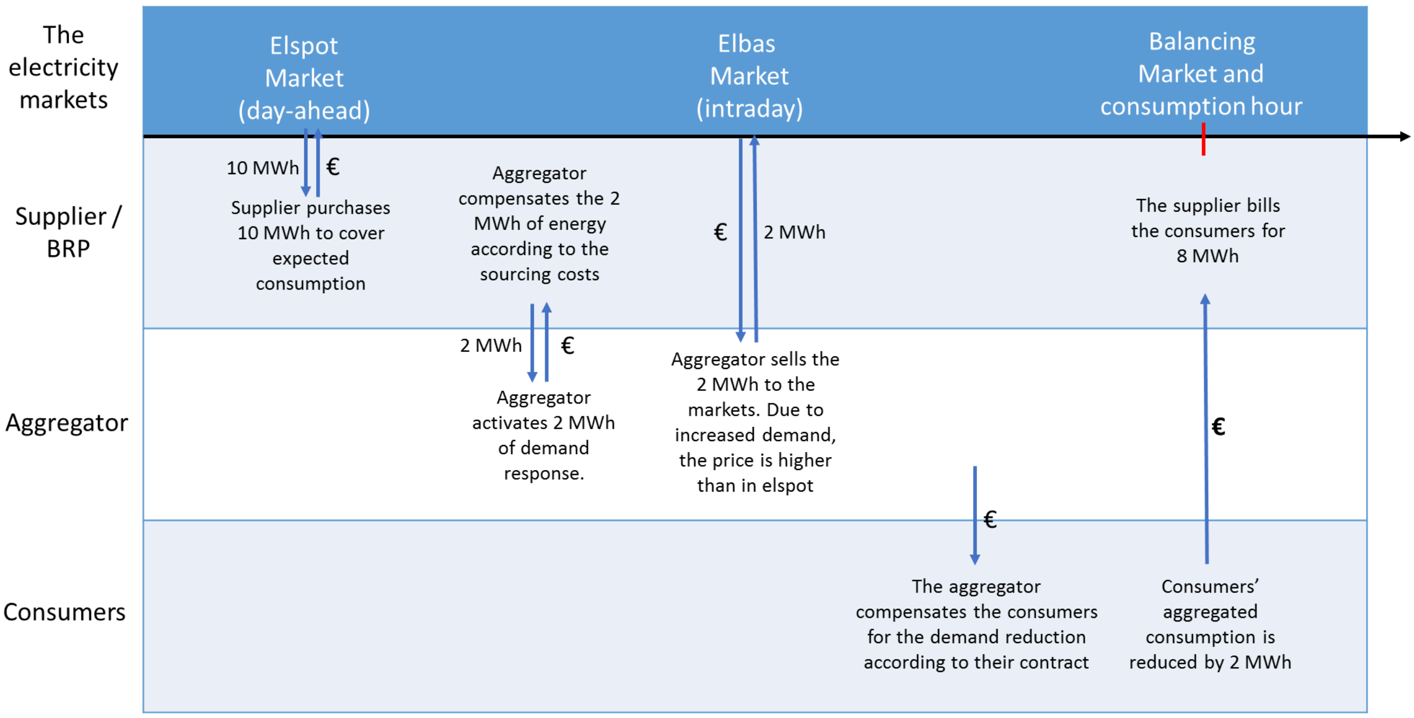

Figure 17. *The monetary and energy transactions between the BRP/supplier, aggregator and the consumers in a demand response event according to the corrected model*

It should however be noted that the corrected model does have an effect on the suppliers' profit, because reducing the amount of energy sold to the consumers also means that they are unable to charge the contribution margin from the customers for the part of energy which is sold to the aggregator. According to the model, only the sourcing costs will be reimbursed and thus introducing a separate aggregator might not be viewed as a positive change among the current suppliers. The fact that a supplier would lose some profits is an understandable motivation, but does not suffice as an argument for preventing changes. Especially when these changes would enable a more diverse supply in the markets and more efficient operation. It could also be argued, whether there is even need for a separate compensation for the sold energy to the supplier. There is currently an ongoing political debate regarding the rationale for having such payments in the European Commission based on the idea that the payments reduce the aggregators' revenues too much compared to the net benefits as discussed in Chapter 3.1.1. In the end, it all comes down to the questions of whether there is need for having third party aggregators in the demand response markets and the assessment of the ratio between the profits of doing so and the cost of making the required changes in the markets. The model does in fact require some changes in the balancing calculations in order to correct the supplier's balance for the part of resold energy. These changes and the related expenses are discussed further in Chapter 3.2.1.

The need for having third party aggregators is indeed recognized, and a central part of allowing flexibility resources to be treated on an equal basis with existing resources in the full range of electricity markets (Smart Grid Task Force 2015) (ACER 2014). Introducing the possibility of a separate aggregator is very likely to encourage the adoption of demand response services among the current suppliers. This is because there now would be a possibility for a new entrant to assume part of the current suppliers' profits. In addition to this, introducing new players to the markets will increase competition as a whole, which will further enable the advancement of adopting demand response as a resource as described in Chapter 2.1. What is however found to be the most important thing is to understand that enabling third party aggregators might provide unexpected new entrants an access in the markets. Demand response, compared to traditional energy production and supply, is a very different method requiring partially different resources and knowledge. Should an innovative company be able to produce for instance software or a device able to optimize the consumption of electricity at a low cost, it can be argued, whether there should be an easy possibility for them to realize this potential without having to take the whole burden of the supplier.

On the other hand, the current supplier could in fact also be interpreted as being an aggregator as it is, which brings forward the argument of why would we want to introduce an additional separate and similar player in the markets. The supplier is in fact gathering together a large group of electricity end-users, and optimizing their consumption – just as an aggregator would. To continue this reasoning, if demand response is able to offer better compensation, ergo a higher price in the markets, wouldn't the suppliers be naturally willing to offer it to the markets themselves? According to market economics, the participant aims for the most profitable means of operation and it is evident that every supplier would be interested in offering demand response if the compensation is at a desirable level (Wangesteen 2005) (Parkin 2014). There are two main questions regarding this thought; Are the current suppliers able to create and provide demand response services themselves, and can the balancing responsibility requirements of a market participant be interpreted as a barrier for entry in the markets.

At the current price levels the profit margin of demand response can be considered to be very low, which can be assumed to hinder the development of flexibility services or at least the interest to these projects among the current suppliers (NordPoolSpot 2015a). Even though the price paid for electricity would increase, it should also be considered, whether a supplier has the capabilities for producing this kind of service. Creating new operating policies in electricity supply companies, which are used to working according to the current principles might prove out to be problematic. In addition, the profitable solution for demand response services might be based on sophisticated professional knowledge regarding software, single board miniature computers or home automation which might be out of the core competence of the traditional suppliers (Halfacree 2012) (Pralahad and Hamel 1990). If there is no willingness or lack of capabilities to develop the requisite technologies regarding profitable demand response among the current suppliers, and we offer no possibility for new entrants to come to the markets, the adoption of market based commercial services will presumably be very slow. Also because of the potential to decrease the revenue the suppliers make, the reception of this model can be expected to be somewhat objecting. As mentioned, it should however be kept in mind that reaching the optimal situation might come at the expense of some of the current market participants and that some negative effects can be considered acceptable provided that they produce a net benefit as a whole.

On the other hand, when thinking about the network requirements as an entry barrier it should be assessed, whether the burden of fulfilling the requirements of a BRP actually is too demanding. Why couldn't the aggregators simply assume the role of the supplier if they are capable of offering similar products at a more profitable cost level? According to the current market legislation, it is stated very clear that each electricity market participant is responsible to produce or purchase electricity which covers the usage and deliveries during each balancing period (The Finnish Government 2013). In addition, each operator in the electricity network needs to fulfill the requirements, which are set to ensure the fluent operation of the grid (The Finnish Government 2009). Regarding this, it would seem contradictory to allow one single market participant to operate without fulfilling the requirements of the other market participants. This is also conflicting with the ambitions of a level playing field, which means that all market players are subjected to the same rules (Kraus 2005) (P. Joskow 1989) (Eurelectric 2015). In any case, enabling separate third party aggregation would require redesigning the market legislation and the rules of balancing responsibility, which are bound to create some expenses. The situation is apparently somewhat challenging. On one hand, enabling third party aggregation is encouraged on a very high level as a profitable means to achieve the market benefits. On the other, this will definitely not come without some expenses due to the changes in the current scheme.

When facing this kind of a situation, with two different options, special attention should be given to quantifying the end result of the different scenarios. If it can in fact be verified that there are substantial gains to be made by allowing third party aggregation and the current suppliers are merely avoiding change in order to protect their current revenue streams, the changes should definitely be made. There are multiple studies regarding the net benefits of demand response in the European markets as a whole focusing on the potential of the various demand response schemes combined, but what is still missing is a numeric estimate of the effect of enabling a third party aggregator in the Nordic electricity markets (Gils 2014) (EWI 2012) (Booz & Co 2013). For this reason, it would be recommended to conduct a further study, which would simulate the situation at various electricity price and demand variables before making the decision of applying the compensation model. The aim of this would be to estimate the expected benefits, which could then be compared to the expenses that applying the required changes would cause.

The benefit of the corrected model is its relative simplicity, even though implementing it would require changes in the balancing model. Implementing demand response schemes according to this model would likely enhance the adoption of demand response resources among the current suppliers since the model enables the third party to compete for the flexibility provided. For instance, a recent PJM Market Activity report stated that 82% of the demand response capacity in that market is provided by independent aggregators. It has been also recognized that no market has been able to implement demand response successfully grasping the full potential without having third party aggregators, and without combining the individual customer's pooled flexibility, it might be difficult to operate such a scheme in a profitable manner. (PJM 2015) (SEDC 2015a) (SEDC 2015b) (Makkonen and Lahdelma 1999) At the same time, the exact quantitative benefits of the model as a whole in the Nordic markets remain unclear, and the validity of having a market participant operating in the markets without balance or network responsibility can be likely to cause some issues. It is also important to note, that the model does not apply to markets, which do not remunerate energy such as capacity markets, reserve markets or other demand response functions, which are outside the scope of this study (SEDC 2015a). The functionality of this model can be achieved in day-ahead and intraday markets or balancing products with energy payments, which is why the suitability for the Nordic electricity markets can be expected to be fairly high, should the required changes in the policies be made. The corrected model addresses the treatment of separate third party aggregators, and can be implemented in the Nordic market structure, which is why it can in fact be recommended as a solution. In addition, the model can be expected to be relatively easy to implement because of the high extent of smart metering in the markets. The realized flexibility would however still need to be compensated in the balancing model, which would mean that there is a need to include a mathematical separation in the balancing calculations of the flexibility to neutralize the error. The measurement and verification of the demand response events is discussed in Chapter 3.1.2. While the corrected model can be considered to be a suitable option for the Nordic electricity markets regarding demand response, special attention should be given to assessing how well it can perform compared to the intrinsic expenses that occur while introducing this model. It would be rational also to assess the effect of the reverse payments to the revenue of the aggregators. There is no use in implementing a model, which aims at enabling third party aggregation, and at the same time makes it financially impossible.

The *contractual model* and *cooperation model* have very similar qualities, as they both are based on the aggregator and supplier working in some kind of cooperation. The differences stem from the actual arrangements of working together, whether it is conducted as a separate third party empowered by a contract or as a close partner. For this reason, these two models are addressed simultaneously.

Regarding the problem of uncompensated balancing errors, these models can be considered to be the optimal solution. As addressed in Chapter 2.1.3, the balancing error, is the difference between the purchased electricity and the actual delivered electricity. The interaction between the parties removes this problem, because of the close communication and planning regarding electricity sourcing. The aggregator is responsible for estimating the amount of demand reduction it is able to produce and for what kind of price for each hour similarly to the suppliers estimate the consumption. This estimated amount of energy can then be reduced from the required electricity to be sourced in the markets by the supplier. Because of this shared forecasting, there will be no additional error in the balancing due to activating demand response bids, which means that there would be no need to change the current balancing model. An another alternative would be to work independently and agree on the compensation level for the balancing error in the contract.

There have been arguments to whether also operating according to the cooperation or contractual models pose an entry barrier for the new aggregators because of the supplier / BRP dominance over the situation. In both of these models, the aggregator has to agree to the terms set by the other party. On the other hand, this party is also the one actually potentially suffering from the participation in demand response if the compensation for the balancing error is not properly set. Considering this, it would seem justifiable that the supplier has a stronger stand in the negotiations. On the other hand, if the aggregator is not satisfied with the demands of the supplier, it can also apply for the balance responsibility status and become a supplier themselves. This would mean assuming the whole operations of a supplier along with offering the aggregation services. This kind of transformation would mean that the scheme would fall under the category of the cooperation model even though there actually is only one market player. Similarly to the aggregator's possibility to assume the suppliers' responsibilities, the model does not in turn limit the supplier from making the decision to offer aggregator services if they think that would be the most profitable way to do it. This would naturally further enhance competition between the parties. Consequently, the risk of an aggregator turning into a competitor would likely enhance the current supplier's willingness to cooperate instead of creating a competitor. In addition, the cooperation of the actors each concentrating on their own area of expertise might actually be a benefit instead of a risk. (Schilling 2013) (Pralahad and Hamel 1990) Because of this reasoning, the setting in these two models should not be interpreted as a barrier for entry.

If we are to operate demand response services according to a model, where two separate companies are working in cooperation such as in the contractual, cooperation or compensation model described above, special attention must be given to the roles and responsibilities of each of these parties. (SEDC 2015a) Both of these models rely on having contractual arrangements between the market parties, which further highlights the importance of the specifics determined in this contract. The European Commission's expert group on demand response has stated that standard contracts should be put in place to ensure smooth contractual process, fair financial adjustment mechanisms and communication procedures between the parties. (Smart Grid Task Force 2015) Concerning the role of the energy regulators in the electricity markets, defining these procedures would be a tangible step towards implementing demand response at a larger scale. By determining the various different mandatory aspects that need to be taken care of in order to successfully operate demand response services would naturally facilitate the easy adoption of demand response. There however still needs to be a distinction between determining the market aspects one has to agree on and actually enforcing certain agreements. The aim of determining this kind of standardized contracts is not to limit the participants' possibilities for creating novel operating procedures. Instead, the main purpose of these contracts would be to merely define the aspects, which have to be taken care of while leaving the choice of how to agree or compensate for these aspects to be decided between the participants. This would mean that the standard agreement would act as a sort of a guidance for the agreements to avoid undesirable outcomes or effects in the markets. As long as the matters defined in the standard contract have been taken care of or agreed on, any additional contracts would be left to be decided by the parties depending on their own wishes and capabilities.

Based on this argumentation, the most profitable market model would consist of the co-operation, corrected and contractual model, out of which the participant would be free to select the most suitable mode of operation. Operating according to these enables the participation of a wide range of resources, which seems to be evident in order to obtain the full benefits of demand response. It should be emphasized that the main idea in this market layout is not to impede the operations of the current suppliers, but instead encourage competition by allowing all the potential resources take part. In addition to redesigning the market model, it would seem profitable for the Nordic energy regulators to form a guideline, which would act as the standardized contract for demand response between the parties. In the case of a single supplier providing demand response services according to the cooperation model there is no need for having such contracts since the supplier is the only provider of demand response. In these cases the guideline could however have an instructive role on the agreement between the supplier and the customers, which actually perform the flexibility.

3.1.3 Measurement and Verification of Demand Response

As demand response is to be adopted in the Nordic countries on a bigger scale, we need to have sufficient means for verifying the flexibility conducted by the consumers. The purpose of this chapter is to assess the current methods for measuring demand response and the possible need for regulatory intervention, or guidance. There are multiple means for calculating the response, and it probably is required to have a common policy for the whole market area. The study analyzes the various methods, giving a suggestion to be adopted in the Nordic markets.

According to the definition in Chapter 1.1, demand response is the change of electricity consumption in reaction to a signal. In other words, the amount of load curtailment in demand response is the difference between the actual observed load and the load that would have occurred otherwise. This brings about an issue of determining the assumed level of load if there were no efforts at reducing the load by flexibility. In order to appraise the economical compensation for the response, there has to be a valid procedure for verifying the amount of response in megawatts. In contrast to the electricity consumed by end-users, which can be precisely measured, demand response is however by definition subject to some error, which should not be ignored, nor exaggerated. (Goldberg and Agnew 2013) The calculation of the response in any case very important, since it acts as the basis for calculating the price paid for the DR participants. Estimating the load that would have occurred without DR higher than it really would have been results in over-compensation for the response. Analogously, a lower estimate reduces the payments and might lead to customers not participating in demand response in the long run (AEIC Load Research Committee 2009). Before introducing demand response programs in the Nordic markets, it would be thus required to define a common approach on how to manage this intrinsic problem. Let´s first take a look at the measuring principles.

There are various methods for assessing the amount of demand response. Since the aim is at defining the operating principles for demand response market participants, the focus here is on measuring and verifying the flexibility on the individual customers' level. There are also tools for measuring the impact of demand response for large groups of consumers, which is more suitable for estimating the response potential of a single market area etc. These mass market demand response measurement methods are however out of the scope regarding the study aims, and therefore will not be addressed.

In order to estimate the amount of reduced consumption, one first has to determine the timescale for such an event. This is typically referred to as a demand response event, which can be defined as the time periods, deadlines and transitions during which demand response resources perform. The significance of such a definition is to set the points of time, between which the response is calculated using one of the methods introduced further. To measure the load reduction during this timeframe, one has to collect or calculate the following two main components; *Baseline consumption* refers to the amount of electricity the consumer would have consumed without a signal to reduce consumption and *actual consumption* stands for the amount of electricity the consumer actually consumed during the DR event. Both of these are presented in **Figure 18**. The amount of load reduction, ergo demand response, can be calculated as the difference between these two components. (AEIC Load Research Committee 2009)

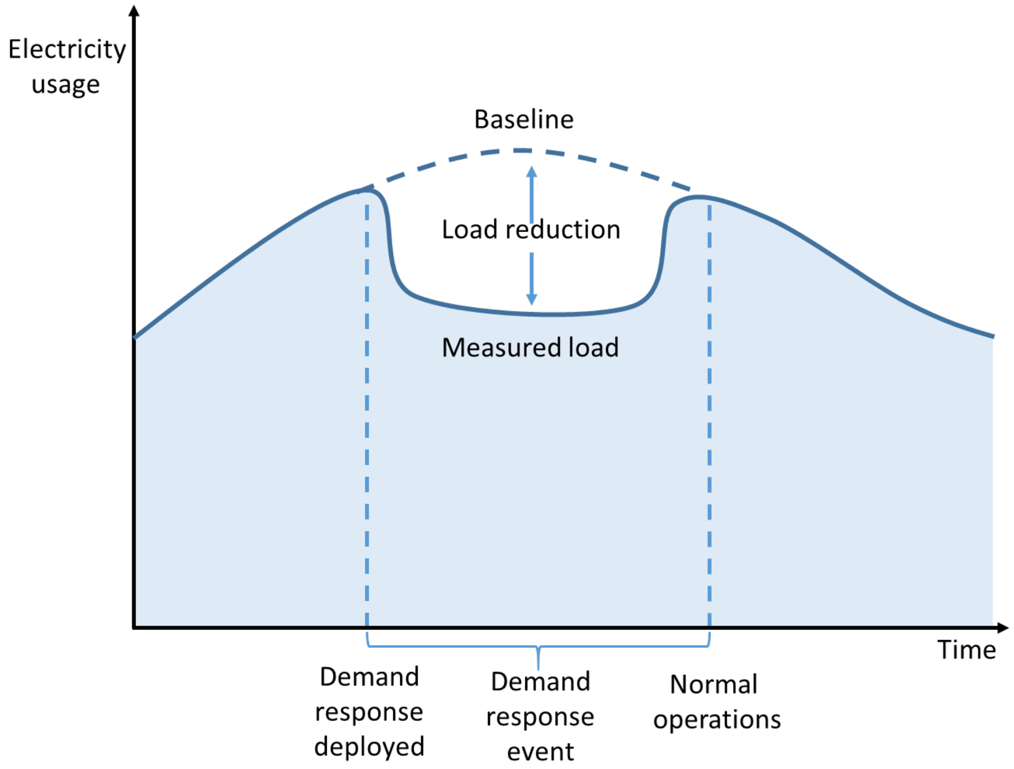

Figure 18. *A demand response event and the baseline. An elaboration based on (AEIC Load Research Committee 2009)*

In the Nordic electricity markets, the adoption of smart meters is high and thus the electricity consumption can be accurately measured for most of the consumers. Hourly and remote metering is possible in most market areas, although there are some differences in the adoption level depending on the country. (NordREG 2014) For this reason, the focus of the Nordic regulators should be in finding the optimal solution for determining the baseline consumption.

The baseline consumption calculation method falls under two categories. Type I baseline refers to creating the baseline by using historical metering data, weather or calendar data and is used when specific customer consumption data is available. Type II baseline instead, is based on statistical pooled sampling and is applicable in markets, where individual electricity consumption meters are not available, and the consumption has to be estimated based on aggregated metering. This approach however is irrelevant from the Nordic markets' perspective based on the accurate consumer level metering, and will thus not be discussed further in this study.

There are two common techniques for determining the baseline consumption during a DR event; *day matching* and *regression analysis*. *Day matching* is based on selecting a baseline day or time period, which most accurately matches the DR event and estimating the baseline according to the recorded hourly data. An average of the historical data is used and the baseline estimate is often adjusted according to the current conditions such as weather. (AEIC Load Research Committee 2009) There are multiple day matching methods for evaluating the demand response performance. The study will now introduce some of these widely used day matching techniques and the regression analysis method:

The *Rolling average* method, as described above uses historical metering data, which is weighted to match more recent data. The applicability and accuracy of this method depends on the amount of suitable data to represent the conditions. (Holmberg, Hardin and Koch 2013) There is also an elaborated version of the rolling average method, the *average daily energy usage* method, which uses daily energy consumption to choose which days are included in the calculation and which not. Suitable days for the calculation are determined by comparing the historical consumption to the day before the demand response event. If the consumption is 75% or greater than the consumption one day before the event, the daily data is included in the baseline average calculation. Otherwise the data will be ignored. This method has been used in the New York ISO (NYISO) day-ahead demand response program as well as the PJM demand response operations. (NYISO 2003) Similarly to this, *period averaging* creates baselines by averaging selected historical data, which is considered to represent the current load situation. The method applies High/Mid X of Y baselines, where Y is the number of days prior to the event that are considered and X is the amount of those days having the highest load for High X of Y or middle load for Mid X of Y. These methods have been in use at least in PJM Interconnection electricity markets (High 4 of 5) and Ontario (High 15 of 20). (Holmberg, Hardin and Koch 2013) (EnerNOC 2011) These averaging methods can be considered easy to understand and the averaging reduces the error caused by the variation in daily loads by creating an average consumption curve. At the same time however, this means that the baseline created by these methods does not completely depict the usage pattern of the day in question, which calls for additional market specific adjustments when using this method.

Comparable day or *proxy day* methods try to find a previous day, which has reminiscent circumstances compared to the day for which the baseline is calculated. These circumstances can vary from weather conditions to special holidays. The challenge in comparable day methods is in determining the proper objective criteria for selecting the days. In addition, the method often limits the time for which the calculation can be made because the specific conditions apply only for some periods of time. (Holmberg, Hardin and Koch 2013) (AEIC Load Research Committee 2009) The suitability of the proxy day method can also be considered insufficient, since there is a broad spectrum of different variables affecting the daily consumption and it is thus possible that there is no suitable previous day to be used as the basis of baseline estimation. In addition to the challenges of selecting a suitable day, this method would still require adjustment for the baseline even if a suitable proxy day can be selected and the data is available. Using the *previous day* as the baseline is a simplified elaboration of the proxy day method. The relative simplicity of this method can be seen as an advantage, but the possible major variations in weather or other conditions are bound to create inaccuracy when estimating the baseline.

Another method for determining the demand response baseline is regression analysis, which uses statistical regression analysis to estimate the baseline based on available data. There are various different regression analysis methods based on the type and precision of the data, which can be based on individual end-user measurements or pooled consumption statistics. A basic regression analysis method describes a load for each hour of the day as a function of the conditions affecting the load such as the cooling degree-day or the weekday. Cooling degree day stands for the number of degrees that a day's average temperature is over a specified temperature, which is often the threshold temperature for using the air conditioning. *(AEIC Load Research Committee 2009) (Goldberg and Agnew 2013)* An example of a basic hourly regression analysis load model calculation is presented in ***Equation 2***.

$$\boldsymbol{L_{jdh} = \alpha_{jh} + \beta_{jh} C_d + \varepsilon_{jdh}}$$

where

L_{jdh}	is the load of the customer at j hour of day d
α_{jh}	is the base coefficient for j hour
β_{jh}	is the cooling coefficient for j hour
C_d	is the cooling degree-days for the day
ε_{jdh}	is the residual error

Equation 2*. An example of basic hourly regression analysis load model for an individual user of electricity. (Goldberg and Agnew 2013)*

One of the advantages of regression analysis method for baseline calculation is that the baseline is calculated for each customer separately, which can act as a basis for further analysis of the data and response. Handling each end-user separately also allows for using various different baseline methods at the same time, if for example the basic regression structure is considered to be unfit for some users. The specific nature of this method also enables very weather conditions for very precise areas to be included in the calculation. (Goldberg and Agnew 2013) The disadvantage of using individual regression analysis is the inherent higher level of estimation error compared to using pooled regression analysis, which uses a similar model, but fits a single model across a larger pool of participants using a single set of coefficients and variables to describe the average load pattern. This pooled method however can be considered unfit as the compensation for demand response has to be calculated for each participant separately. Using the pooled model and merely dividing the compensation for the sum of the response might lead to a situation, where some participants are undercompensated while some other participants are free riding and paid too much for their smaller demand reduction. This kind of design error in the forthcoming demand response markets would be likely to cause distortion and net benefit losses as described in Chapter 2.1. For this reason, the pooled regression model should not be considered as a choice for the Nordic markets, especially as there is precise consumption metering available for almost all consumers in these markets.

After introducing the various methods, one should take a look at the suitability of these M&V models for the Nordic electricity markets. The amount of demand response programs is still small, and it should be kept in mind that the experience on baseline calculation represents only a narrow part of the numerous different types of electricity markets and their different features. Does this mean that the lessons mostly learned from the American electricity markets are not applicable for the European or Nordic markets? The methods described above are a set of mathematical or statistical tools, and should be considered as such. The accuracy of these tools in estimating the baseline consumption depends on the adjustment of the different variables according to the local market needs. This however should not hinder comparing the methods with one another, or their suitability for demand response purposes regardless of where they are to be applied. This view is shared also by EnerNOC, which states that failure in matching the variables according to the market and customer characteristics can lead to inaccurate results (EnerNOC 2011). The pros and cons of the baseline measurement options for Nordic markets are catalogued in **Figure 19**.

	Baseline Methodology	Pro	Con
	Rolling average / Period averaging	• Easy method for customer to understand • Averaging takes out the variability in load for the days used to create the average day	• An average load shape created from multiple day load shapes will not totally capture the usage pattern for an event day • The need for a baseline adjustment
Day matching	Proxy day	• Matches a day based on defined variables uniform with event day	• Finding a day based on the defined variables • The need for a baseline adjustment • There might not be a day to use as the proxy day
	Previous day	• Most likely the same usage pattern as the event day • Easy method for customer to understand	• Does not take into account the effects of weather on load • The need for a baseline adjustment
Regression analysis	Individual Regression analysis	• Concept of variable relationship is easy to understand	• Customer understanding of the process used • Selecting the correct variables to use in the model

Figure 19. Pros and cons of baseline methodologies for the Nordic markets. An elaboration based on AEIC Load Research Committee (2009).

According to a recent paper by The Smart Energy Demand Coalition, the demand response baseline calculation should be made using an agreed and robust methodology and that market participants should have a small number of standardized formulas, or ideally one formula, which is applied across whole market area. Emphasis is put on designing a method, which is accurate enough to remove free riding. At the same time, it is recognized that it might be difficult to apply one standardized model to cover different types of demand response activities on a range of different participants. It is also suggested that the design of the standardized measurement and verification method should be based on the existing procedures on other markets by the NRA or by the TSO. (SEDC 2015a)

There are multiple studies regarding the measurement and verification of demand response on different markets, and the findings in these reports reveal how there are various different approaches which are considered as the optimal solution for specifying the baseline level. Based on the variety of these solutions it would seem that the optimal solution is usually market specific for each different market. Hence, regardless of the available information from other markets the question of an optimal solution for the Nordic electricity markets, remains unclear. The optimal outcome should be determined by first taking a look at the existing markets and their solutions. The efficiency of baseline estimation models is relatively easy to determine by using the historical consumption and weather data. A baseline estimate can then be calculated for any given day in the past using the data previous to this day. The calculated result can then be compared to what actually happened on that day. Conducting a large series of computations using different baseline calculation methods for the historical consumption data allows us to compare the accuracy of each method in different market, weather or other conditions. (Goldberg and Agnew 2013) (PJM 2011) (California Energy Commission 2003) After taking a look at the varying methods of calculation, the optimal methods and market conditions can be compared to the Nordic markets in order to find similarities and differences. These market specific features are examined in light of demand response measurement and verification to determine, which markets are most likely to have solutions, which would work best for the upcoming Nordic demand response system. Following this reasoning, the study will now take a look at the baseline estimation methods currently in use, as well as the related studies.

Since demand response is a relatively new method, even the first studies regarding measurement and verification or baseline calculation are relatively new. A study conducted by California Energy Commission (CEC) was one of the first attempts at determining the most accurate baseline using recorded data as the basis for this study. Their research covered data from several parts of the U.S., and the aim was to assess the accuracy of the different baseline methodologies, which are also presented in **Figure 19**. It was concluded that no single approach was able to offer a comprehensive solution for the various load characteristics, stating that: “baseline calculation protocols should provide for alternatives based on customer load characteristics and operating practices”. Regardless of this, the study however revealed some more specific recommendations. Using a rolling ten day window with an additive adjustment based on the two hour prior to the demand response event was found to be the most practical method. Baseline calculation for highly variable loads was found to be challenging as well as the adoption of weather regression due to the increased data handling requirements. (California Energy Commission 2003) (Goldberg and Agnew 2013) Concerning the increase in computing capacity, it might be debatable, whether this applies to the modern electricity markets. On the other hand, the CEC report also concluded that using simple averages with weather adjustments produces nearly as accurate results. The efficiency of the model should also be among the criteria of selecting the baseline method, since overcomplicated models are likely to cause additional costs or at least increased operational expenses.

Similarly to the CEC study, a period averaging method was considered to be the optimal also in a more recent study conducted by the Ontario Power Authority (OPA), which studied the accuracy of the baseline methods focusing on their own demand response program. Differing from the earlier study, the OPA study focused on finding the optimal variables for the period averaging calculations. There were in total 48 different combinations of the averaging timeframe and the selected number or high/mid days. Of all these analyzed methods, there were six combinations, which were able to produce an average error within ± 2 %. These baselines included high 7 of 9 and 10 of 10 hourly baselines corrected with either 4 or 6 hour same-day adjustment. The high 10 of 10 baseline however was considered to be the most accurate option, since this method was able to maintain a very low -0,5 % error on average during the most common event periods. It was also considered to be most accurate for demand response participants of varying magnitude. (Goldberg and Agnew 2013)

The rolling average was also recommended by a PJM study, which ranked the baseline estimation tools' performance as well as the expected administrative costs they bring about (PJM 2011). This should be considered as an important viewpoint due to demand response applications' relatively low profit margins caused by the low electricity prices (NordPoolSpot 2015b). Determining a reliable and fair baseline estimation method is of essence, but it should be kept in mind that the excessive accuracy will result in excessive costs, which can outweigh the expected profits. Concerning this, PJM concluded that the high 4 of 5 baseline method with additive adjustment was among the most accurate baselines without additional operative costs to implement. Some other methods such as the 10 of 10, or a method used by the ISO-NE were actually found to be more accurate, but the increase in accuracy could not justify the additional costs of doing so. It was also found that the rolling average method performs well using a subset of time periods such as 10 of 10, high 5 of 10, high 4 of 5 and middle 4 of 6 with adjustment. These methods however were inaccurate in estimating baseline for end users with variable loads. It was suggested that end-users with variable load should be segmented separately under a different evaluation method or market conducts. (PJM 2011) This is a fundamental discovery regarding the Nordic electricity markets. The upcoming demand response market consist of a large group of households, as well as industrial consumption units. To promote demand response, the market design should create a level playing field for all competitors as suggested by SEDC (2015a). In light of PJM's discovery this level playing field might actually mean applying a different set of rules for different kind of participants against the intrinsic assumption. Demand response is compensated according to the difference between metered consumption and the baseline, and if the baseline deviates from the "would have been" –consumption level of not participating, the participant is either over- or undercompensated for participation. This possibility of not receiving adequate compensation can be expected to hinder the participation in DR programs. On the other hand, inaccurate demand response verification methods could also bring about exploiting of the situation by allowing participants to enjoy the compensation without actually even changing the level of consumption.

The studies above focused largely on the appropriate baseline calculation method and its accuracy. A study sponsored by the California Public Utilities Commission (CPUC) sponsored an analysis of the baseline estimates focusing more on the baseline adjustment methods. The study parameters included universal or optional application of same-day adjustments, which was possible in some of the various demand response programs in the study. Universal adjustments mean that the baselines are adjusted for all demand response portfolios, while optional adjustment means that the aggregator can elect prior to an event whether to apply same-day adjustments or not. The computations were made using multiple different adjustment caps for the same-day. The adjustment caps refer to the minimum or maximum level of weather or other adjustment compared to the calculated baseline level. A total of eight adjustment caps were tested including no adjustment, ±20%, ±30%, ±35%, ±40%, ±50%, -50% to 200% and unlimited adjustments. It was discovered that most aggregator programs underestimate the demand reductions. The study concluded that applying any kind of same-day adjustments increases accuracy universally, and a large share of the underestimation was caused by the aggregator's decision not to apply the same-day adjustment for all customers in their portfolio. As a result of this, universal same-day adjustments were recommended, as they almost always increase the accuracy of the estimate. (Freeman, Sullivan & Co. 2011) In light of the CPUC study, the case for demand response baseline adjustments is strong, and it would seem illogical to allow the aggregator to decide whether or not to apply adjustment for the baseline calculation. The background of this policy can be expected to be a result of end users with stable consumption patterns regardless of other conditions. In consideration of this study and the expected inaccuracy, adopting baseline adjustment for all participants seems reasonable. This is also supported by a separate study conducted by the ISO New England (ISO-NE 2011) (Goldberg and Agnew 2013). It should also be noted that the imprecision of the baselines reported in the CPUC study might be a result of the aggregators' gaming in order to optimize the situation on their behalf (EnerNOC 2011). Gaming refers to a situation, where the market players are able to manipulate the demand response system in order to pursue additional benefits for themselves. In this case gaming might mean the aggregators choosing not to use an adjustment method in order to maintain the baseline at a higher level than what it should be. An increase in the baseline level results in a higher estimate of the demand response event, which in turn would generate excessive profits for the aggregator. This kind of action distorts the markets, leading to an unfavorable outcome regarding economics or social welfare as described in Chapter 3.3.2, and should be prevented by the demand response market rules regarding the baseline calculation methods.

The design of the baseline evaluation method has a major significance in the accuracy, as described above. An American regional transmission operator, ISO-New England (ISO-NE) studied the effects of continuous demand response events on demand response baselines (ISO-NE 2011). Most demand response baseline applications are based on mathematical models, which try to evaluate the baseline building on the historical data of the previous days. This brings about an issue, when there are continuous subsequent events. The models require data from the previous days, but in some cases this data might not be available and the accuracy can be expected to decrease as the model is forced to use older data. ISO-NE recognized this kind of occurrence in their demand response programs, when looking at the day-ahead load response program. The participants were able to offer load reduction at such a low price, that the bids cleared every day. These cleared days were removed from the baseline calculations according to the local market rules, which made the baseline frozen at the level of the first day of clearing of the series. The longer the response events were, the more inaccurate the baseline estimate was due to seasonal drifting of demand. This "baseline freezing" proved to be problematic, and no optimal solution could be discovered for this gaming of the aggregators. The report concluded that it is possible to develop policies, which improve the baseline accuracy by limiting the days a customer can clear during a particular timeframe, or alternatively using the contemporary meter data for the baseline calculations. If accurate baseline methods addressing the gaming issue could not be created, then market rules constraining the participation of highly variable loads in demand response programs will have to be developed. (ISO-NE 2011) While regulating the acceptance of some participation of some actors might correct the issue to some measure, this solution seems somewhat inadequate. Limiting the amount of possible demand response bids seems irrational considering the potential gains of the system as a whole. Furthermore, the demand response markets are dependent on actors capable of alternating their consumption on a large scale. Preventing their acceptance to the markets is likely to cause a large scale loss of capacity on these markets. All things considered, flexibility regulation in general should be enabling instead of restricting. In addition to this, the demand response structures in Europe and the Nordic countries have been suffering from an inadequate number of participants. While gaming against the system is a major issue, it might be worthwhile to look at possible more advanced baseline estimation methods for prolonged timeframes of demand response events. Another solution could be to compare the magnitude of the baseline calculation gaming and distortions to the total gains of having demand response during these times in the first place. If the gains outweigh the disadvantages, some deviations from the optimal baseline might even be considered acceptable. Regardless of what the solution will be, it should be based on a thorough examination of the situation and a specific calculation of the net effects.

There is also an additional challenge regarding constant demand response events and determining the baseline, for which there apparently at the moment is not a proper solution available. As described in Chapter 1, demand response should be considered as shifting the consumption to an alternative time period instead of merely lowering or increasing the amount of consumption (CEER 2014). What this means in practice is that during the so called recovery period after the event, the electricity consumption is higher or lower than it would normally be to compensate the change in the load to catch up with the normal level of operations. This recovery period is visualized for both increasing (valley filling) and reducing the load (peak clipping) in **Figure 20**.

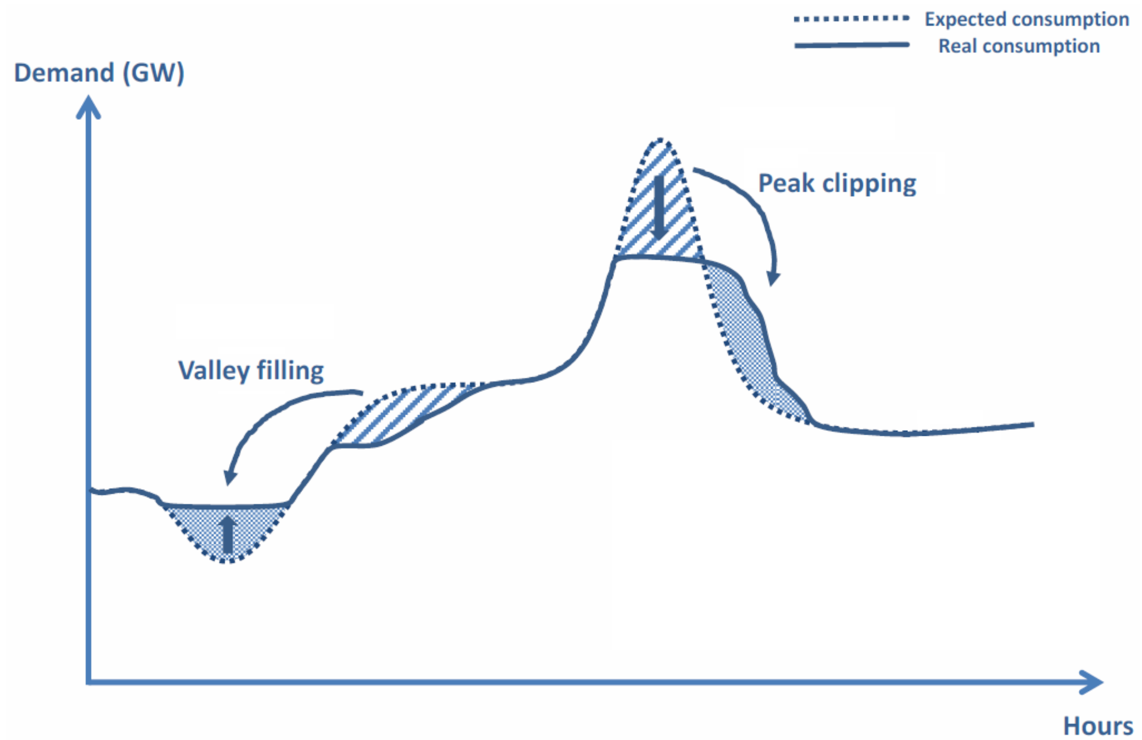

Figure 20. *The recovery period of demand response events. Adapted from (CEER 2014).*

Considering subsequent demand response events and baseline freezing, this would mean that even though there were periods of non-event data in between the consequent events, the data acquired during these periods might still be too imprecise to represent a normal load situation. For this reason, it should not be used as the basis for the baseline calculations, or at least there might be need for adjustment before using the data. According to the theory of recovery period, the error should constantly increase, as the demand response period becomes longer because the gap between normal operations is constantly growing. However, the idea of increasing error might not apply, if the consequent demand response events are conducted by multiple alternating individual end-users operating for instance through a single aggregator. In the case of multiple alternating participants, this problem could be solved by examining the level of consumption in the level of end-users instead of the aggregator and comparing similar end-user's consumption patterns. Regardless of this, the problem regarding one participant's continuous participation and baseline calculation remains. Removing the possibility of continuous demand response bidding might remove the problem, but at the same time it would limit the number of participants as described above. In light of this, additional adjustments merely for these cases might be more suitable, but they would add the complexity of the regulation and demand more computing capacity adding to the costs. Considering the relatively low level of participation, the distortion in baseline calculation during short non-event periods should be estimated and weighed against the total benefits of acquiring demand response from participants capable of continuous reductions. As with any new procedure, there probably will be need for further adjustment after having some actual experience. When the prevalence and error of baseline adjustment using data from a short non-event period is known, the disadvantages can be scaled and compared, after which the decision between increased calculation and restraining the bids can be made.

Based on the arguments presented above, it would seem that the optimal solution for baseline calculation in most of the demand response markets is based on different variations of the period averaging method. This is also supported by EnerNOC, which has stated that High X of Y –baseline calculation with day-of adjustment is the most accurate baseline calculation for most applications. Regardless of this, it is also recognized that there are typically some system-specific considerations that should be taken into account when designing the baseline calculation model. (EnerNOC 2011) These considerations can be seen as referring to preventing the demand response participants' gaming or baseline freezing issues as well as the required adjustments for local climate conditions. Similar recommendations were also given by PJM, as they concluded that the optimal solution will depend on the cost structure as well as market-specific considerations (PJM 2011). Based on EnerNOC's and PJM's statement, as well as the suitability of this method on most markets as described above, it is concluded the optimal baseline calculation for demand response in the Nordic electricity markets will be a variation of the period averaging method. Determining the market-specific variables for the averaging period and the weather and other conditions' adjustment coefficient however would most likely require further analysis. Special attention should also be given to preventing participants from gaming the system. The possible restrictions regarding continuous demand response bids should be estimated as the commonness of this kind of situations in the Nordic markets can be determined and their impact on the total welfare can be estimated. One solution for the gaming situation could be to define limits for the maximum days of consequent demand response events. Concerning the amount of exact metering there is in the markets, the baseline issue could also be solved by comparing the baseline with the actual consumption curve of a similar group of customers, which however are not offering flexibility. A similar group of end-users would in these cases act as a reference group.

3.2 Applying Demand Response in the Nordic Markets

After examining the various market models, one should evaluate the implementation of the optimal demand response method in the Nordic markets. The chapter assesses how the new regulatory model would work, and evaluates the suitability of the models for offering demand response to the markets.

3.2.1 The Suitability of the Demand Response Models in the Nordic Electricity Markets

The various possible market models for demand response are considered in Chapter 3.1.2. The analysis focused on reviewing the interactions between the market participants and the possible configurations between the market parties as well as the disadvantages these schemes might have. Three different possible market models were identified as beneficial or suitable for adoption in the markets; the cooperation model, corrected model and the contractual model. The previous chapter did not address how easy the implementation of these models would be and what kind of changes they would require, which is the core of this chapter. The study will now take a look at the models and their suitability in the current market configuration. Since the contractual and cooperation model are relatively similar, they will be covered simultaneously, while the corrected model stands on its own in this analysis.

Let´s first take a look at the corrected model, since it differs from the current market configuration more than the other solutions. As described, the corrected model is based on the aggregator compensating the sourcing costs of the re-routed electricity to the supplier and correcting the incurred balancing error in the balancing calculations for the part of activated demand response. Currently, the balancing is handled by the Nordic TSOs according to a common balancing model based on two separate balances; the production- and the consumption balance as described in Chapter 2.1.4. Each BRP is responsible for constantly maintaining a balance between the production/sourcing (production balance) and consumption/sales (consumption balance) of electricity. This model based on two balances has been in use since 2009, and would require some changes if third party aggregation will be adopted according to the corrected model. (Fingrid 2015) In order for the new model to function, the balance of a supplier/BRP has to be corrected by subtracting the electricity reduced by demand response to remove the unfair costs, which would otherwise occur to the BRP. What this would mean in practice is that the consumption balance calculation should be modified so that it includes an additional subtraction for the demand response reduction. This subtraction would be conducted according to the actualized demand response which is then verified according to the methods described in Chapter 3.1.3. The calculation method including the suggested demand response subtraction is presented in **Figure 21**.

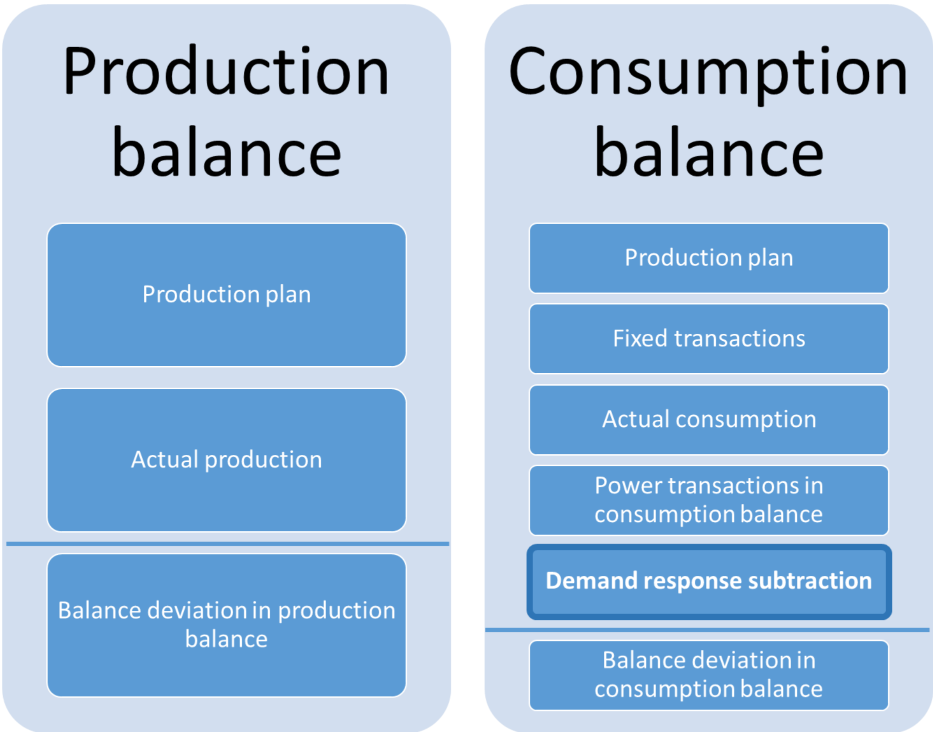

Figure 21. *The required change in the balancing model according to the corrected model. An elaboration based on (Fingrid 2015)*

It is evident that adding a new feature to the established balancing calculation does not come without expenses. The required modifications require testing and planning, and the additional calculations would likely require additional processing and data storage capacity. The Finnish Energy, an interest group for the companies specialized in production, transmit and sales or energy and energy related products has questioned the relevance of third party aggregation based on the resulting costs and major changes in the balancing model (The Finnish Demand Response Forum 2015). It is perceivable, how such a major change can enhance negative outlooks among the current market participants, regardless of the method's pronouncement as one of the most important solutions regarding energy efficiency by the European Commission (Smart Grid Task Force 2015). Whether this is simply a case of contrarianism among the current market leaders to protect the benefits, or a valid counter argument should not be decided on a hunch or putative figures (Krugman 2009). The costs of having a new method at this scale without special knowledge of the data systems and its requirements are very hard to estimate without an extensive study. It is however reasonable to assume that the costs can be significant. In any case however, the focus should not be merely on the the resultant costs, but instead on the relation between the scientifically calculated estimated costs and benefits on a longer timescale. Due to this reasoning, it is recommended to conduct a study, which would examine the costs and benefits of third party aggregation according to the corrected model in the Nordic electricity markets. Adopting the corrected model would as well require reassessing the electricity market law regarding the regulations about balancing responsibility in the grid. An overview of the required modifications is presented in Chapter 3.3.3

The reason for having a balancing model is to ensure the power balance between each market participant so that we preserve the stability of the network. (Fingrid 2015) (Wangesteen 2005) For this reason, we cannot examine the situation merely as correcting the unfair costs by using a mathematical calculation. Every demand response event has an effect on the grid, which should be taken into account. The electricity network and its technical limitations however do not fall under the scope of this study. Regardless of this, it has to be mentioned that before applying new demand response models, special attention should be given to assessing the effects it has on the grid and the possible costs that would occur. It should be understood that due to the nature of demand response, the effect for the network is likely be a positive change. Demand response has a tendency to remove peak pricing and valley filling as described in Chapter 3.1.3., which lowers the network requirements.

The contractual and cooperation models can be considered to be significantly easier to implement in the current market framework compared to the corrected model. Their functionality is based on the current supplier's established operations in the markets supplemented by the knowledge of an aggregator functioning as a subcontractor or a close partner and being responsible for operating the demand response services for the supplier/BRP. Since there aren't any new participants in the electricity markets, the requirements of operating according to these two models are in fact already in place and there should be (The Finnish Government 2013). Compared to the corrected model, the suitability of these two models is very high and the expected costs are minor. Concerning the fact that these two models are already in place, it is important to consider why we haven't seen such services offered at a large scale and what could the energy regulators do to encourage the adoption of these services. The recommended actions for regulators are addressed in Chapter 4.5

The question of the suitability of the suggested market models is largely dependent on the balancing model, and as described, the corrected model requires some changes in the current system. Consequently, there is currently a common project among the Finnish, Swedish and Norwegian TSOs to facilitate a uniform balance settlement; the Nordic Balance Settlement (NBS). After the project has finished, each BRP operates according to similar rules and service regardless of the country. What this means regarding demand response is that for the part of the market areas participating in NBS, there would be need to create the rules for aggregated demand response only once compared to the current system, where there are minor differences between the countries. (NordREG 2014) The need for making changes in a smaller number of different balancing rules reduces the amount of work required, and therefore also mitigates the cost level. The planned lauch of the NBS is estimated to be in early 2016. Currently, it seems that the new joint imbalance settlement rules are focusing mostly on handling the harmonization of the various balance settlement procedures in the participating countries and addressing the potential changes due to demand response seems to be somewhat overlooked or left for further revision. (eSett 2015) This is understandable regarding the challenge the TSOs are facing, but it could be argued, whether the possibility of adopting third party aggregation rules while assessing the common rules would be beneficial.

3.2.2 The Division of Demand Response Profits

Demand response can provide profits for multiple different parties as described in Chapter 3.1.1, and there is some question regarding the division of these benefits between the parties. To understand this division, the profits are divided into two separate sections; the in-market profits and the out of the market profits similarly as in **Figure 13**.

The out of the market profits are externalities accruing to parties other than the market participants which did not choose to incur this benefit, such as the possible network benefit. The magnitude of these externalities are assessed according to models such as the framework introduced in Chapter 32 to ensure profitable net benefits as a whole. This calculation makes sure that we end up in a profitable situation, and due to the nature of these benefits internalizing these benefits is often not beneficial. (Parkin 2014)

The in-market profits however pose more questions regarding the division of income. These profits refer to the monetary gains for the market participants; the supplier, the aggregator or the consumer, which is providing the flexibility. The proper level of compensation for the supplier is discussed in detail in Chapter 3.1.2, so what is left is the division of income between the third party aggregator and the end-user or consumer of electricity. (Parkin 2014)

The division of captured surplus depends on the nature of the market participant, depending on their *business orientation* and the *competitive pressure* they are facing. The business orientation refers to whether the participant is profit based and thus aiming at maximizing its own profit or not. The aggregators as commercial actors aim at increasing their overall profit from demand response. At the same time this means that they are willing to reduce the end-users’ share of the profits. The sharing of profits is related to the competitive pressure a company is facing. What this means is that the higher the competition is, the fairer the distribution with the end-users will be. High competition leads to reducing the own profits in order to attract more customers, and while competition is absent, there is no need to provide these incentives. (European Commision Think Project 2013) (Smart Grid Task Force 2015)

What this means is that the payments for demand response to the flexibility providers should depend on the contracts between the participants much like in standard electricity contracts. As discussed earlier, demand response is dependent on having multiple actors and competition. If we manage to form a functional demand response market, the end-user is free to tender the flexibility among the aggregators or suppliers to get the best profit. Currently we are facing a situation, where the profit margin for demand response is very low and the compensations thus even lower. This can however be expected to change depending on the electricity prices, level of renewable generation and other changes in the markets. It should be also understood that when operated properly, demand response can be unnoticeable for the end-user of energy. The changes in room temperatures for instance after switching the heating off are so slow, that any short flexibility bids will go unnoticed (Ruotsalainen 2008). If there is no perceived disadvantage, even minor compensations can be considered to be worthwhile.

3.3 Energy Regulation and Demand Response

Energy plays a major part in a modern society, which is partly the reason for having such comprehensive rules and regulations in the markets. This chapter takes a look at the reasons for regulating any economical schemes, and the preconditions for designing fair new demand response regulations for the electricity markets. The ambitions of regulation in general, and the recommendations for demand response serve as the fundamental rules, according to which each of the recommendations given in this study have to apply. After taking a look at the preconditions for creating new regulation, the chapter continues by analyzing the expected and observed market distortions or failures related to introducing demand response as a new resource to the existing electricity markets. These deviations are the fundamental reason for having regulative guidance in the electricity markets. After introducing the market distortions, a look is taken at the specific changes, which are required to create functional and balanced new markets.

3.3.1 The Aim of Electricity Market Regulation and Designing Unbiased Rules for Demand Response

The Nordic electricity markets are a liberalized area as addressed in Chapter 2.1.3. Regardless of the markets being open, there is still need for legislative guidelines and regulations. Regulation in general refers to the government or a governmental body applying laws, rules or orders to regulate economic interactions in order to reach social or economic objectives. The purpose of regulation is to protect the public from the negative consequences of imperfect competition or to eliminate a company from abusing market dominance. (Partanen 2010) There are numerous different market-related features typically causing market failures, which justify the need for regulation, such as natural monopolies, information asymmetry or protection of infant industries. (Kraus 2005) Regulation in the case of electricity markets should thus be considered as a necessary tool for correcting the errors, which are quintessential in such schemes. The aim of regulation is to ensure proper functionality of the market system, which in the end is also the ultimate goal of this study. Designing proper regulative framework for demand response in the Nordic electricity markets can however be a challenging task. The markets consist of numerous different parties, each having their own interests as described in Chapter 2.1.4. The upcoming regulation should at the same time ensure the adoption of demand response at a level playing field compared to other sources of energy, without at the same time discriminating any of the current actors. As described in Chapter 2.1.3, the Nordic electricity markets have been operating since the 1990's, and the current market operating policy is the result of several consequent reforms. It has been recognized that during market reforms, following the basic emerged blueprint is likely to lead to well-functioning markets. Any major deviation from this path is expected to lead to unintended consequences, which in turn would create new challenges. In addition to this, any electricity market reform has proven to be challenging and complex, regardless of possible previous experiences and lessons learned. (Kraus 2005) (P. Joskow 2006)

According to the reasoning above, it is clear that the required demand response reform in the electricity markets should be designed as a part of the current market operating principles. This however does not clarify the actual goals of these new policies. As discussed in Chapters 1.2 and 2.1.2, demand response is an important and valuable method for increasing energy efficiency and solving balancing issues. The energy regulators should aim at creating policies, which facilitate the efficient take-up of demand response in order to achieve these benefits. The European Agency for the Cooperation of Energy Regulators (ACER) conducted a study regarding the potential and current state of demand response in the European Union (ACER 2014). Based on this study, several regulatory principles are recommended in order to ensure efficient adoption of demand response. Let's now take a look at each of these principles individually, and assess their possible execution in the Nordic markets. These principles, and the fact that the solution should be based on the existing market design serve as the basis for creating the new regulatory scheme, and each change should be in line with both of these.

- Market design should be tailored to take account of the demand flexibility, which is able to provide value. It is unlikely that demand response will be provided in useful quantities, or arise naturally by itself, if there are no specific market arrangements, which support this kind of response. (ACER 2014) In practice this means that from market perspective there would be no difference between megawatts produced by increased production or reduced consumption. From the regulatory perspective, this recommendation means that there should be a standardized method for offering demand response products to the markets.

- The demand response participant should be properly compensated for the services provided to the market. Unless demand response is given a similar opportunity to earn fair remuneration for the provided services, it is unlikely that it will be provided at a sufficient level. (ACER 2014) This does not however mean that demand response should be incentivized, or overcompensated. The energy resources should be able to compete on the market on an equal basis and the compensation level should be determined by demand and supply. A more thorough analysis of the price formation can be found in Chapter 3.1.1.

- The compensation for demand response demands a plausible method for verifying the amount of flexibility delivered. Without proper measurement and verification methods, there can be opportunities for taking advantage of the system abusively, and unfair compensation might be paid for fabricated flexibility. (ACER 2014) The challenge is in finding a common method to be adopted in the whole market area among all the participants. The optimal methods for demand response verification in the Nordic markets are studied and explained extensively in Chapter 0.

- Electricity users should be assisted in realizing that they have the opportunity to participate in the demand flexibility markets, and make actual savings for doing so. Domestic electricity users rarely engage with electricity markets and also infrequently make decisions, which would change their patterns of energy usage.

(ACER 2014) Informing about demand response is an important factor of achieving functional demand response markets, and in line with the Finnish national regulatory authority's strategy statement (Energiavirasto 2012). The most effective means of encouraging demand response by communication would likely be by creating a uniform communicating strategy between all the market participants. In the case of Nordic markets, this could be easily achieved by cooperating in a project as a part of the active Nordic energy regulator's organization, NordREG. There is currently also an internet portal encouraging domestic customers to tender their electricity contracts (Energiavirasto 2015). Creating a similar service listing the purchase bids for demand response would clarify the financial gains and likely encourage more participants to offer demand reduction (SEDC 2015a). Currently, the price level of electricity in the Nordic markets is considerably low (NordPoolSpot 2015a). The price level can however be expected to change, as the European grid becomes more integrated and more countries bid for the Norwegian hydro power (IEEE Spectrum 2015). A higher electricity price will lead to increased savings for participating in demand response programs, but setting up the required framework and informing the potential participants should be done well beforehand.

- An unconflicted party should be in control of constructing the market model and regulations affecting demand flexibility. There are multiple market participants, which earn income by providing other sources of flexibility and thus are conflicted from a neutral approach, since it potentially is contradictory to their interests. (ACER 2014) For each member country, there is a national regulatory authority in charge of the enforcement of legislation as well as the construction of these market models in cooperation with each other in NordREG. Fulfilling this recommendation should hence come naturally in the Nordic electricity markets. There might however be some conflicting views or contradictory measures for enforcing demand response legislation regardless of the Nordic countries' mutual understanding. These markets consist of both EU non-member and member countries, which operate under the European Commission's ordinances.

- Demand flexibility resources should be treated equally compared to other sources of flexibility. The value of flexibility is avoiding investement in other sources of capacity, and the full useful extent cannot be delivered unless it is equally treated. (ACER 2014)

- If necessary, system standards should be revised to be more consistent with a market where there are multiple sources of flexibility. The standards are typically designed in an era, without many sources of flexibility, which can result in disqualifying some efficient resources. (ACER 2014)

Regardless of the ultimate regulatory market design to adopt demand response resources' participation in the markets, it should be understood that regulation can by no means reach an ultimate optimal point, where it can be considered to apply the best solution in the changing environment. Instead, the whole regulatory scheme consisting of the regulator, companies, customers and legislators interact with each other by feedback mechanisms, which in turn results in a further change in the regulative structure. (Partanen 2010) What this means regarding demand response is that the aim is to design an optimal model, and possible further changes should be considered to be an acceptable and required modifications resulting from a change in the whole market.

3.3.2 Market Failures and Distortions

Regardless of the multiple benefits of demand response, there are some indications of possible negative effects of applying demand response programs. The design of the regulatory framework should be applied to minimize or remove the negative effects when necessary. Let's now take a look at these distortions and in the markets created by enabling flexibility services.

One of the potential market distortions relate to the actual benefits of having demand response systems operating in the markets. According to a Danish study analyzing demand response based on microeconomic theory, there is a risk of actually losing social welfare by introducing demand response in the market system. This is based on an idea, that there is a generator, which has excessive market power, and introducing demand response would increase this power to operate in his own interest. The researchers admit to the fact that the results are still preliminary and indicative. However, if the arguments hold true, whether introducing demand response creates a welfare gain or loss would depend on the amount of companies participating. According to the study, if two companies are competing, welfare could be increased by introducing demand response. While having three or more companies, the result would be opposite. (Andersen 2006) There are similar arguments regarding the net benefits of demand response in Chapter 3.1.1, and it would seem that instead of viewing the technology as a comprehensive solution for all the market problems, demand response should instead be addressed as a tool, which might not be suitable for all solutions. The advantages of this technology are always sector-specific depending on the local market players and electricity production facilities. This is likely to call for an analysis of the impacts as a whole before considering the introduction of these systems on a wider scale.

There is also some dispute to whether the effect of having demand response has a negative environmental effect. It is argued, that under the current regulatory environment, demand response profits are disproportional with the benefits, and more attention should be paid to the levels of CO_2 emissions in these schemes. The emissions' impact depends on the generation mix of the market. If the base load plant has intrinsically higher emissions than the peak power plant in use, activating demand response can increase the total emissions. (Van Horn and Gross 2013) It is clear that the demand response programs should take into account the effect on CO_2 emissions and ensure that the end results are in line with the overall goals of having demand response in the first place as defined in Chapter 1.2.

The issues described above are in fact recognized also by the European regulators, and they publicly state that there are market cases, in which the profitability of demand response is compromised. According to ACER's estimate, the disadvantages are rather the result of an already compromised market environment. Due to these market faults, adding additional market configuration might further increase his problem if not correctly addressed. It is however noted, that the risk of perverse outcomes should by itself be reduced the more liberalized, integrated and competed the markets are. (ACER 2014)

In addition to the previous potential net benefit losses, demand response can potentially have a major negative effect on the economy of power systems. An example of this is the arbitrage created in capacity auctions, which are in use in the PJM markets. Every three years, an auction is held in order to secure the reliability of the system. Each power producer can bid in the auction for a plant to be included in the scheme. After an accepted bid, the plant is required to be able to deliver electricity if requested. Should this be for some reason impossible for the actor, they have to purchase replacement capacity in an incremental auction from the other producers. Demand response is allowed to bid in the capacity auction as if it were traditional supply of electricity. The demand response bids are typically substantially lower, since they have lower costs due to the nature of the technology and low need for technology. As a result, the traditional energy producers are pushed out of the market. The arbitrage is created, when the incremental auction is held. The prices in this second auction are typically lower than in the first auction. This has led to a situation, where the demand response providers first bid for a high price, then purchase the replacement capacity from the second auction pocketing the difference. (James 2013) It is clear, that operating based on a market arbitrage is likely to be prevented in the long run, which is why this kind of actions are most likely hindering the adoption of demand response schemes. There are no such capacity mechanisms currently in the Nordic electricity markets, apart from the similarities between the power reserves, which are used only for situations, when the electricity markets are unable to cover the demand. (Energiavirasto 2015) (The Finnish Government 2011) (NordREG 2009) It should however be noted that similar exploitation can occur, if demand response resources are considered by the same precepts as generation. What this means, is that the participation rules for flexibility should be revised before introducing it to a reserve or a market segment. Special attention should also be given to the verification and measurement of these resources. It should also be noted that verifying demand response according to the methods introduced in Chapter 3.1.3, and obliging the implementation according to the flexibility bids is likely to reduce this problem by forcing the actors to create the agreed capacity by reducing demand instead of sourcing additional energy. This would also remove the arbitrage, and thus correct the market operations.

This problem regarding a market based arbitrage is in fact a result of treating demand-side resources on an equal basis with supply-side resources, which is an understandable, but fallacious conclusion. The design of the electricity markets was designed to accommodate supply-side resources and demand response differs from these resources as discussed in Chapter 3.1.1. This further enhances the need of clarifying the current market conduct rules and recognizing the required changes. The gaming issue discussed in Chapter 3.1.3 and the welfare losses related to it are closely linked to the risk of market arbitrage and fall under the category of market distortions or failures. Gaming in this case refers to a market participant exploiting the current regulations. It is a result of inadequate market conduct rules, which then leads to an undesirable outcome as the individual players operations aiming at maximizing their profits has in fact an opposite reaction in the total benefits.

Gaming and the other disadvantages described in this chapter should be considered as regulatory challenges, which need to be solved. It should be kept in mind, that there are deficiencies in every market. All of the European stock exchange markets have to be constantly monitored and market conduct rule breaches are often observed. The situation is the same regarding flexibility, but naturally introducing a completely new scheme is bound to create some unexpected issues. The first steps in avoiding the problems as made clear in this study are understanding the fundamental difference between supply increase and demand-side flexibility, and determining the required market conduct rule changes accordingly. The possible new distortions arising during the introduction of demand response schemes should be considered as natural occurrences in the development of a new market scheme and left to be resolved in the

3.3.3 Required Modifications in the Electricity Markets

The study examined the main challenges of applying demand response schemes in electricity markets in Chapter 3.1. This research however considers the challenges from a wider perspective. The issues are viewed and solved by considering them as separate theoretical challenges, which in real life are actually derived from regulatory and legislative stipulations. This chapter takes a look at the prequisites for actually making the required changes. The aim is at recognizing the general deficiencies in current market rules, which would be in need of revising in order to accomplish the suggested changes investigated in this study.

Traditionally the day-ahead market has been the center of energy markets. The common operation practice in the day-ahead energy market is such that the market operator receives offers from generating units to provide energy, which are combined with the purchase bids forming the price level. Traditionally the demand of electricity has been considered to be relatively passive, and the electricity production has to be scheduled to follow the varying demand. (Parvania, Demand Response Participation in Wholesale Energy Markets 2012) As we are facing more flexibility in the demand-side as well as improvement in the metering technology, there is a need to revise the market rules and structures to allow the new resources to operate.

The current market legislation does not take into account third party aggregators' demand response and currently the flexibility offers are accepted only by the supplier. By examining the policies, it becomes evident that the legislation regarding balancing has to be revised, if third party aggregators are to be allowed operation in the markets. (The Finnish Government 2013) Currently the situation however is such that the changes in the market rules should be conducted on the European level according to the procedures governed by the Capacity Allocation and Congestion Management (CACM) (European Commission 2015). In addition, there is an ongoing harmonization of the Finnish, Swedish and Norwegian balance settlement, Nordic Balance Settlement, according to which the potential balancing methods should be agreed on. (eSett 2015) (NordREG 2009). The Network Code on Electricity Balancing (NCEB) is estimated to enter into force during 2016, which may restrict the possibilities of having separate Nordic initiatives regarding balancing (ACER 2015).

In addition to the legislative and regulative policies, changes would have to be made to the NordPool market conduct rules to enable third party aggregators' participation in the market operations correspondingly. (NordPoolSpot 2015c)

4 Conclusions

Demand response is a compendious resource, which will most probably have a central role in the future endeavours for a more efficient and modern smart grid structures. As described in Chapter 1.3, the approach for clarifying the optimal end result in this complex system with intertwined and possibly competing participants is based on analysing smaller segments. The optimal solution is then discovered by combining these partial solutions, provided that they are not exclusive from one another. It is however important to understand that reaching a flawless solution in such a complicated setting is arguably challenging or even impossible. Instead, the aim should be at discovering the optimal solution, which improves the current market setting. In this case the optimal solution refers to the maximum total benefit to the system as a whole, which also has acted as the main rationale in analysing each separate partial solution.

This chapter consists of a summary and conclusions of the findings regarding the thesis aims and research questions. Due to the significance of the study as a guideline for the financier, Energiavirasto, the study concludes by presenting the individual recommendations for actions to be taken by the regulators regarding demand response.

4.1 The Value of Flexibility

In order to operate a functional demand response scheme as a part of the electricity markets in a beneficial way, there has to be a solid understanding of the value of the utility. The price should reflect the value it can generate to its purchasers, or otherwise there is a risk of distorting the markets and ending up in a counterproductive situation regarding the net benefits. As discussed in Chapter 3.1.1., there has been an active debate concerning the true value of demand response and whether there is need to regulate the price level.

Due to the pioneer role of the North-American demand response markets, the most advanced methods stem from this origin. According to the Federal Energy Regulatory Commission (FERC), demand response resources should be compensated at the full locational market price, which is a price level used in the nodal pricing system. This is not completely analogous with the Nordic electricity market structure, but the procedure to estimate the economic effects was found to be adaptable also in this market. What the FERC's decision means in practice is that we should accept the price determined on the markets for this resource without any additional regulative adjustments. Statements supporting this view have also been given by the European Commission.

The main argument to regulate the price level of demand response instead of accepting the market price was found to be based on an idea that paying the full market price results in excessive compensation for the flexibility and net benefit losses. This is an economic argument based on the idea that paying the full market price for demand response resources while the customers at the same time avoid paying the marginal energy rates is producing a compensation for the resource which actually exceeds the benefits. This overcompensation would then lead to excessive amounts of demand response and a sub-optimal market situation. Following this logic, the proponents of this view suggest correcting the price by subtracting the cost of generation from the price set in the markets. The study concluded that such regulatory alterations in the market price are likely to impede the adoption of demand response, which can be considered difficult to operate in a profitable manner with the current price levels. The argument was also found to be somewhat in dichotomy with the idea of accepting demand response as an equal resource as defined by the European Commission.

Even though the arguments for subtracting the retail tariff from the market price were found to be erroneous, it was discovered that there might be some veritability in the conviction. The reason for having demand response programs was found to be a result of the retail tariff structures intervening with the market, which results in the inadequacy of the demand curve to accurately represent the real demand. This could be avoided by having real-time pricing for all customers, but due to the market setting and customers' wishes it is seems impossible to achieve. What this means is that the markets have an inherent structure creating some inefficiency. It was discovered that even some of the opponents of the retail rate subtraction for market price admit the formal correctness of paying less than market price for demand response. Regardless of this, it was however explained that there is always a wide range of inefficiencies in the market, and the subtraction would result in a suboptimal situation from a wider perspective. This view is also shared by the European regulators. It was discovered, accepting the full market price is likely the most suitable for the Nordic electricity markets concerning the adoption of demand resources. The study however concluded that the issue is political and still requires further analysis.

In addition to the pricing, the research clarified that one of the central attributes regarding demand response valuation was the assessment of its net benefits as a whole. What this means is that there is a need for assessing the total effect the flexibility has and then considering the possible restrainment of the detrimental offers from taking place. There are such measures in use at the moment, but the focus of these existing methods was however found to be likely too narrow and focusing only on a small part of the participants. Regarding the Nordic markets the optimal solution was presumed to be based on assessing the full financial value of demand response.

In addition to the methods currently in use, the study discovered a framework for comprehensive demand response evaluation, which could be used as a template in designing the necessary net benefits evaluation. This framework is based on two different segments focusing separately on the participants in the demand response market, and participants which are not in direct involvement in the market but can gain profits from the activities. The framework assesses these two segments using computational modelling based on market economics and cost/benefit analysis, and estimates the total social surplus accordingly. The input data required for these calculations is obtained from real electricity markets, which can be considered to be readily available. After this calculation, a decision is made to whether to dispatch the cleared demand response or not. This decision is made depending on its total effect, rejecting any flexibility action, which would result in a negative social surplus.

Due to the adaptability of the model and its comprehensive extent, it was discovered that it is likely to provide an appropriate basis for creating a net benefits test model for the Nordic electricity markets. For this reason it is recommended to be used in the development of the demand response valuation schemes.

It was however recognized that applying new structures for evaluating the net effect of demand response bids will likely cause expenses and face opposition, depending largely on the division of expenses among the market participants. It should thus be emphasized that demand response is and will be an increasingly important resource. In addition, the adoption of flexibility has been clearly concluded in the European Commission. Making any kind of major changes in the existing market configuration is bound to create expenses, and the situation should be considered on a longer timescale; there is need for making the changes and having the net benefit valuation computations is likely essential in reaching an optimal outcome. Otherwise we face the risk of implementing demand response without actually gaining all the potential advantages.

4.2 Market Model for Demand Response in the Nordic Electricity Markets

The question of an optimal market model is discussed at length in Chapter 3.1.2, where the main challenge reflects the question of discovering a pattern or patterns, according to which the potential demand response resources could be brought to the market in the most undisruptive manner. The study recognized the most challenging aspects to be the possible overlapping responsibilities regarding network balancing and hence the fallaciously directed costs to the BRP, encouraging the adoption of new flexibility services and the role of separate third party aggregation.

With regards to market economics and according to the findings, it seems plausible that the optimal solution for the basic layout of the market participants – the market model – consists of multiple separate models, which would enable the participation of all demand response resources. The possible market configurations were mapped, and three of them were identified to be most suitable regarding the aspirations of demand response regarding energy savings and market efficiency. Each of the market participants would be able to operate their organization according to one of these three policies in the markets and thus the recommendation for the optimal model is the combination of the following operating policies. This is also in line with creating a level playing field for possible new entrants.

The three suggested models fall under two different categories; offering demand response via the current supplier/BRP or offering demand response services using a separate third party aggregator. The selected models; cooperation-, contractual- and corrected model are each somewhat different from each other and offer a solution for bringing a variety of different demand response resources to the markets, which is found to be essential. The cooperation model is largely based on the current market structure, where the supplier simply includes the demand response services to its service portfolio, whether they create the flexibility themselves or by purchasing flexibility services from an affiliate. According to the findings, this model is the easiest to apply, but consequently also limits the participation of possible new entrants in the markets. The contractual model is a variation of the cooperation model, in which the aggregator is in liaison as a separate party authorized by a contract, which defines the procedures between the two parties. The difference now is that the aggregator is a separate third party with its own responsibilities regarding balancing. The third model, the corrected model, enables a separate third party aggregator to operate without the consent of the current supplier of the flexibility providing customer. This is based on the idea that an aggregator could enable a better and more profitable use for the available electricity. Introducing such measures however requires assessing the proper level of compensation to cover the actualized sourcing costs for the supplier/BRP, but no more than that. While the model has been contested by the current suppliers' proponents as described earlier, it is very important to enable the participation of new entrant independent aggregators to achieve the benefits. This view has ample support among the unbiased high-level stakeholders. According to the findings, enabling third party aggregation is also likely to have an inherent and encouraging effect regarding flexibility services. The possibility of an aggregator to capture part of the suppliers' sales forces the current operators to offer such services themselves. By removing this entry barrier, the successful service provider in the long run will be decided based on the efficiency of the operation instead of the established position just as it should be according to market economics. While doing so we will also reach a more optimal outcome regarding total benefit. There is also an ongoing political discussion regarding the rationale for the payments for the energy to the supplier paid by the aggregator, and its effects on the amount of offered demand response. Special attention should be given to estimating the net effects in each of these scenarios before making the decision.

Regardless of the evident market benefits, it is found to be important to assess the magnitude of changes required in order to apply a new structure in the markets. Operating according to the models including a separate aggregator (contractual or corrected model) means that there is actually a need to divide the balancing responsibility for two separate parties. Otherwise the balancing error created by the aggregator activating would bring about an unfair cost, for which the BRP would be liable. Dividing a balancing responsibility is very different from the current balancing model, and correcting the situation would require including some additional calculations. This correction would mean in practice subtracting the amount of activated demand response from BRP's balance to remove the accountability for the part of aggregated flexibility. Based on the findings and the major potential of third party aggregation, it seems to be very important to bring this third party resource to the markets. There are multiple studies regarding the benefits of aggregated demand response. It is however found to be important to conduct a quantitative study estimating the benefits and expenses of changing the balancing model and allowing third party aggregation especially in the Nordic Electricity markets.

4.3 Measuring Flexibility

In order to successfully operate a demand response market, there has to be a specific and reliable method for verifying that a reduction in the energy usage has actually been realized. The study shows, that the significance of the verification and measurement of demand response are very central concerning the adoption of flexibility, since the financial transactions would be based on the amounts of electricity measured and verified by the standardized method. According to the observations in the study, reliable and transparent measurement also results in lower risk for the demand response operators as well as enhances the market participation of this resource.

The amount of demand response is defined as the difference between the observed load and the load that would have occurred otherwise without the flexibility, calculated over the specific time period of the demand response event. This brings about the issue that the level of consumption during normal operations without flexibility is by definition unavailable. The solution for this was found to be creating a baseline level of consumption using mathematical, historical or statistical methods. The baseline is an estimate of the consumption that would have occurred without demand response, which is then used as a basis for calculation.

The research discovered several different methods for determining the baseline. The most suitable method for assessing demand response was found to be using a rolling average method, which would be adjusted by a High X of Y method. This method determines the number of rolling days out of which the number of Y highest values will be used for the calculation. Specifying the optimal numbers to be used in the Nordic markets depends on the market specific factors, which can be discovered by statistical analysis of the different options using historical data. The most suitable rolling average baseline calculation methods were able to produce an average error of ± 2 %. During the most common event periods, an average error of ± 0,5 % could be reached.

It was also concluded that additional same-day adjustments such as adjusting the calculation according to the consumption two hours before the event always increase the accuracy of the calculation. These additional adjustments are recommendable, but it should be understood that additional calculation increases the complexity and thus also the costs of operating these measurement services in the demand response markets, which currently operate under a low profit margin.

It was discovered that there is a risk of demand response providers to take advantage of the system by exploiting the measurement methods based on a rolling average. This gaming of the system can potentially result in the baseline freezing at a certain level if the demand response bids are activated for a specific timeframe in consequent days. This could be prevented by designing regulatory measures such as limiting the amount of consequent bids or using reference groups to determine the baseline in these cases. Before applying restrictions for continuous demand response bids, their prevalence should however be estimated. Special attention should also be given to calculating the effects regarding total welfare.

4.4 Further Research and the Significance of this Study

It has become evident that demand response is a more complicated subject than one might think at a first glance. The focus of this study is merely on the wholesale electricity markets, but the same resource has significant resources for instance also in congestion management, other network uses as well as frequency or supply reserves. Due to the fact that demand response is still underutilized and relatively new in the markets, there is need for conducting similar studies regarding the adoption of demand response in other uses of this technology as well.

Concerning the scope of this study, further studies would be required especially concerning the Nordic markets. As there is a relatively large coverage of smart metering currently available, demand response should be more easily applied than in most of the other markets. This and the developed liberalized markets could enable the Nordics to adopt the role of a pioneer. There are currently multiple studies regarding the benefits of applying demand response. Contradictory to the view of the Nordic market as a suitable market for early adoption of these resources, most of these studies are focusing on individual Central European countries or USA. It would seem that conducting a quantitative study focusing on the Nordic potential would be needed.

Many of the studies regarding the benefits of demand response are focusing merely on the price savings. Since the benefits however stem from multiple different sources, it would be more reasonable to try to estimate the full benefits on each specific market. For instance what seems to be missing is a study estimating the difference in expenses using scenarios where demand is applied and not. This study could be based on the expected future investments in generation or network, which could be avoided by introducing demand response. As it is, the profit marginal for demand response is low. This is however subject to change depending on the electricity prices and flexible production capacity available, and we are currently facing a shift towards a higher penetration of renewable production. In addition, home automation is taking major leaps forward and the future role of electric vehicles in electricity networks remains unclear. In addition, the development of internet of things and the development of smart grid systems are bound to mitigate the expenses of applying the technologies demand response necessitates. It would seem to be lucrative to assess the significance of flexibility in different expected future market settings regarding the price of electricity and the rate of adoption of the mentioned technologies. The required investments in modifying the current market model might seem expensive at present time, but the outlook might differ concerning the forthcoming changes.

It should be understood that demand response is a resource, which has decreasing marginal benefits depending on the amount of flexibility provided. What this means is that the first participants to implement the technology have larger benefits than the rest. The changing benefits and a large number of data makes the number of computations very high, which is why most of the studies have taken a significantly simplified approach resulting in more inaccurate results. There is currently only one single and very recent study, which encompasses this by examining the value of shifting demand as a response to prices (Corbishley 2015). Further more specific studies would be required.

Regarding the adoption of demand response resources, it should be understood that energy production is a very political subject. As the demand response services can potentially displace some major industrial operators' facilities, it is likely that the subject will bring about political debate. It should be thus understood that the adoption of these new resources – even profitable ones – is not based completely on the computational benefits, but there might be more complex challenges regarding protectionism, politics or conflicts of interest that need to be resolved.

All in all, demand response should be considered as a utility suitable for some situations instead of a comprehensive solution for market inefficiencies. This highlights the importance of assessing the overall effects before applying any changes in the current market structure. The research in this study clarified the mode of operation, according to which the markets should be organized to enable efficient adoption of this resource in the Nordic electricity markets. In addition to quantifying the potential, it is recommended to conduct pilot projects which turn these measures into tangible experiences, which in turn are likely to provide further understanding of the subject. This thesis should be viewed as a preliminary study on defining the basic principles of operating a market incorporating demand response, based on which further research on the market structures can then be elaborated. There is uncertainty regarding the future of the markets, and hence also on the role of flexibility. Regardless of this, it is evident that demand response has significant potential and the work to unleash these resources continues.

4.5 Recommendations for the Nordic Energy Regulators regarding the Implementation of Demand Response Resources

According to the request by the financier of this research, the study concludes by presenting the recommendations for actions based on the findings. This list of recommendations applies to the scope of the study as described in **Chapter 1.4**, disclosing the most beneficial actions and operation modes for efficient adoption of demand response resources in the Nordic electricity markets as well as the requisite changes in the policies.

I. Assess the functionality of the framework for estimating the net effects of a demand response bid

The study proposed a framework for estimating the net effects of each demand response bid. The suitability and possible reformations for the model regarding the Nordic markets should be assessed. Special attention should also be put on assessing the costs and level of constant work required in using the model to ensure that establishing such a scheme would actually produce a beneficial outcome.

II. Revise the policies to adopt third party resources to participate in the electricity markets

The current market conduct rules and policies support only demand response provided by the suppliers. It was discovered that allowing third party aggregated demand response providers is necessary to obtain the full benefits of the scheme. For this reason, the regulations should be redesigned to support also this resource. This would require interaction between the legislators, regulators as well as all the market participants in making the needed alterations in the laws and power exchange rules.

III. Evaluate the cost of making the required changes (balancing, policy)

The participation of third party aggregation in the electricity market is recognized as a required resource and there are some major changes needed in order to enable it. On the long run it would seem worthwhile to make these changes. On a shorter timescale however, the cost of these changes should be assessed. In addition to this, special attention should be given to the division of these expenses in a justified manner.

IV. Assess the requirements and develop the standardized contracts between the market participants

The reason for having standardized contracts is to ensure that all the required factors have been taken into account before starting to operate the new scheme. These standards also play a major part in lowering the barriers of entry to the markets. The standardized processes can be considered to be important for all demand response models, but especially for the third party aggregation. The aggregator has to be able to operate independently but in some kind of a cooperation with the supplier/BRP, which is potentially at the same time its competitor. The regulators define the standardized contracts to enable smooth operation of the market. In short, the standardized contracts could consist of defining the volumes, compensation, data flows as well as a method for resolving any upcoming issues between the participants.

V. Develop a method for specifying an accurate level of compensation to cover the sourcing costs for the supplier / BRP for third party aggregation

These costs should reflect the full sourcing cost as closely as possible covering the cost of purchasing the electricity for the part that was dispatched as demand response and "resold" by the aggregator.

VI. Redesign the balancing model to support third party aggregation

In order to enable third party aggregation, there has to be a method to correct the balancing error that would otherwise be created to the supplier/BRP. In practice, this means that the aggregator assumes the balancing for the part of demand response and any other balancing error would be the responsibility of the supplier such as it currently is.

VII. Conduct a simulation study assessing the quantitative potential of third party aggregation in the Nordic electricity markets

While the role of independent aggregators in demand response is recognized, it would seem to be necessary to conduct a further cost/benefit study regarding the situation. The study would simulate the situation at various electricity price and demand variables obtained from the real Nordic electricity markets. The results of this study would act as a guideline before making the decision of actually applying the compensation model. The aim would be to estimate the expected benefits, which could then be compared to the expenses created in applying the required changes in balancing or policies to enable third party aggregation.

VIII. Investigate the market specific variables to be used in the measurement and verification of demand response

The most accurate method for defining the demand response baseline used in measurement of demand response events was found to be the rolling average method. The individual variables regarding the timescale used for averaging, selecting only a number of these days or circumstantial factors such as weekdays, consumer habits or weather are market specific. These factors should be clarified by experimenting different combinations using simulations based on the real market data to discover the most accurate method to be adopted.

IX. Assess the risks of gaming and design policies to prevent harmful manipulation of the measurement and verification methods.

It was concluded that there is a risk of demand response market participants gaming the system for instance by freezing the baseline level with multiple actualized bids for the same hour during consequent days. The potential risks of exploiting the market should be investigated further and preventive measures should be applied. Special attention should also be given to the possibility of redesigning the rules, should new counterproductive loopholes be discovered by the participants.

X. Encourage the adoption and knowledge regarding demand response services among consumers

Energiavirasto, among the other Nordic energy regulators has a role in promoting demand response services to achieve the benefits. When properly conducted, participants could simply enjoy reduced electricity bills without even realizing that an event has occurred. These services could be promoted similarly as the regulators are now promoting tendering the electricity contract or having hourly electricity pricing. The standardized contracts described above can also be considered as one method for encouraging the adoption and should thus be carefully designed.

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